PANOCHE/SILVER CREEK WATERSHED ASSESSMENT FINAL REPORT

SEPTEMBER 28, 1998

Prepared for:

PANOCHE/SILVER CREEK WATERSHED COORDINATED RESOURCE MANAGEMENT AND PLANNING GROUP

AND

THE CITY OF MENDOTA, CALIFORNIA

Prepared by:

MCCULLEY, FRICK & GILMAN, INC.
71 Stevenson Street, Suite 1450
San Francisco, CA 94105-2938
(415) 495-7110
FAX (415) 495-7107

WILLIAM LETTIS & ASSOCIATES, INC.
1777 Botelho Drive, Suite 262
Walnut Creek, CA 94596
(925) 256-6070
FAX (925) 256-6076

MFG Project No. 6175

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LIST OF ACRONYMS OR ABBREVIATIONS

AGNPS - Agricultural Non-point Source Pollution Model

ARC/INFO - A geographic information system used to create, analyze, query, and display spatially referenced data

AUMs - Animal Unit Months

BLM - U.S. Bureau of Land Management

BMP - Best Management Practices

USBR - U.S. Bureau of Reclamation

cfs - Cubic Feet per Second

COE - Corps of Engineers

CRMP - Coordinated Resource Management and Planning

DWR - Department of Water Resources

EHR - Erosion Hazard Rating

ft - Feet

FWS - U.S. Fish and Wildlife Service

GIS - Geographic Information System

HEC-1 - Hydrologic Engineering Center **-** 1 (computer model developed by U.S. Army Corps of Engineers)

I-5 - Interstate-5

MFG - McCulley, Frick & Gilman, Inc.

MUSLE - Modified Universal Soil Loss Equation

NHC - Northwest Hydraulic Consultants, Inc.

NRCS - Natural Resources Conservation Service

PSCW - Panoche/Silver Creek Watershed

RDM - Residual Dry Matter

LIST OF ACRONYMS (continued)

RUSLE - Revised Universal Soil Loss Equation

SCS - Soil Conservation Service

USGS - U.S. Geological Survey

USLE - Universal Soil Loss Equation

WLA - William Lettis & Associates, Inc.

yr - Year

ACKNOWLEDGMENTS

The Panoche/Silver Creek Watershed assessment was conducted and this report prepared by McCulley, Frick & Gilman, Inc. (MFG) and William Lettis & Associates, Inc. (WLA). Overall project management, watershed area reconnaissance, study area investigation, and channel incision area vegetation characterization were performed by MFG, and involved the following MFG personnel: Frederick L. Charles, Maria L. Sonett, Brendan Annett, Jeffrey A. Gilman, Sean M. Covington, and Clara Weygandt. The channel incision area study was performed by WLA, and involved the following WLA personnel: Keith L. Knudsen, Edward J. Helley, Carolyn E. Randolph, and William R. Lettis. Other assessment activities were conducted jointly by MFG and WLA.

MFG and WLA would like to acknowledge the contributions of CRMP members and others who provided information for the assessment. Reports, photographs, and accounts of conditions in the watershed were provided by the CRMP, and included the following individuals: Nettie Drake (coordinator), Tim Moore (BLM), Bruce Cotterill (BLM), Charles McCullough (chairman), Dave Durham (NRCS), Don Keathley (NRCS), Dr. Charles Krauter (California State University - Fresno), and others. Kerry Arroues (NRCS) provided the current working draft of the Western Fresno County soil survey for use in the assessment.

Stephen Lee and Monty Lorenz (USBR) assisted in obtaining 1990 and 1998 aerial photographs and 1990 measurements of channel cross sections; Stephen Bradley of Boyle Engineering Corporation supplied data from his files; and Charlie Kratzer of the USGS provided preliminary 1998 suspended sediment sampling and discharge data from the gaging station on Panoche Creek at I-5.

This project has been funded wholly or in part by the United States Environmental Protection Agency Assistance Agreement No. C6999668-98-0 to the State Water Resources Control Board and by Contract No. 7-029-250-0 in the amount of $96,500.00. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency or the State Water Resources Control Board, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

1.0 EXECUTIVE SUMMARY

The Panoche/Silver Creek Watershed (PSCW) is a major source of sediment loading to downstream areas during flood events. The overall goal of the PSCW assessment was to provide baseline information for making informed decisions related to mitigation of this sediment loading. Specific objectives of this PSCW investigation were to: (1) evaluate the rate of soil erosion within the PSCW, and identify influencing factors such as land use and natural processes; (2) identify and rank high erosion source areas; (3) assess the magnitude of sediment delivery into the lower fan area; and (4) develop and evaluate the effectiveness of best management practices (BMPs) for management of sediment production and reduction of sediment loads.

The principal source of sediment transported to the lower Panoche Creek fan is mainstem streambank and streambed erosion near the confluence of Panoche Creek and Silver Creek. Minor sources of sediment transport include natural hillslope erosion in the northern Tumey Hills, the hills near Idria, Griswold Canyon, and the hills west and north of the Panoche/Silver Creek confluence. Natural hillslope erosion has been accelerated by livestock-related denudation of vegetation in upland and riparian areas of the Silver Creek drainage. However, the effect of livestock on sediment loading to Panoche and Silver Creeks appears to be small in most areas, relative to the magnitude of streambank and streambed erosion.

The Panoche Creek channel, downstream from the Panoche/Silver Creek confluence, has experienced dynamic geomorphic change over the past 60 years. For the current study, historical changes since 1924 were characterized, and geomorphic effects of 1998 floods were described. Annual sediment yield estimates for the PSCW, ranging from 500 to 13,500 tons/square mile per year, were computed and compiled. Based on observations of effects from the 1998 flooding, the following trends are noted: bank erosion was prevalent in the reach of Panoche Creek near the confluence; deposition was prevalent in the reach of Panoche Creek downstream of I-5; bank erosion in reaches downstream of the confluence was localized, occurring mainly on the outside of bends; there were short reaches of the channel (several hundred feet long) where the channel migrated tens of feet laterally into the adjacent terrace or alluvial fan deposits in 1998; abundant sediment was deposited upstream of two flow constrictions, the bridge crossing lower Silver Creek and the Fairfax Road bridge; and little hillslope-derived sediment directly entered the channel from slopes downstream of the confluence. Streambank and streambed erosion occurs in other portions of the PSCW, but not to the extent observed near the confluence.

Impacts associated with livestock utilization in the lower elevations of the PSCW were noted for the 1997-1998 grazing season. These impacts were concentrated around drainages in both upland and riparian areas of Silver Creek. Herbaceous plant cover was low to absent in some of the drainage bottoms, and impacts to shrub populations were also noted. Much of the riparian vegetation along Silver Creek is heavily impacted by livestock congregation, and these impacts contribute to bank erosion and disturbance of the native plant community. Outside the heavily impacted areas, vegetation cover was excellent in 1998, allowing many upland drainage courses to act as buffers for potential sediment delivery downstream. Livestock utilization in the western and southwestern areas of the watershed was light to moderate, and was not a significant influencing factor for sediment transport from these areas.

Best management practices (BMPs) were evaluated individually and in selected combinations (scenarios) in terms of their effectiveness, implementability, and relative cost for reducing sediment loading in the PSCW upstream of I-5. From the evaluation of BMPs, it was observed that revegetation in selected appropriate areas, in conjunction with modifications of grazing practices in the highly erodible upland and sparsely vegetated riparian areas in the Silver Creek drainage, would restrict erosion from upland source areas and provide a riparian buffer to reduce the transport of sediment into streams. However, implementation of this scenario would result in a relatively small change in total sediment yield from the PSCW compared to the large amount of streambank and streambed erosion that occurs during major runoff events. Construction of runoff detention facilities in the upper PSCW was also evaluated to address the potential for streambank and streambed erosion. A preliminary analysis shows that implementation of small runoff detention facilities may result in a significant reduction in peak flood flow rates and decreased flood stages. Streambank erosion and in-channel production of sediment would be expected to be reduced as a result of a decreased height of floodwater and potentially decreased flood flow velocities. Therefore, permanent runoff detention facilities in the upper watershed, in conjunction with re-establishment of a vegetative riparian buffer area in the Silver Creek drainage, may provide a major benefit in terms of reducing total sediment yield from the PSCW.

A detailed feasibility investigation is recommended for the detention facility BMP scenario. This evaluation should include a quantification of the effect of these facilities on reduction of downstream streambank and streambed erosion. In addition, to address management of sediment in areas downstream of I-5, a focused, detailed investigation into the feasibility of a floodplain corridor, or other BMPs, is highly recommended.

2.0 BACKGROUND AND OBJECTIVES

The Panoche/Silver Creek Watershed (PSCW) is located upstream and to the west of Mendota, California, and is approximately 50 miles west of Fresno, California (Figure 1). The watershed area, as defined for this watershed assessment work, encompasses approximately 300 square miles upstream of Interstate-5 (I-5), and ranges in elevation from approximately 500 feet at I-5 to 5,000 feet near the upper watershed boundary. The PSCW is located in Fresno and San Benito counties and lies on the western edge of the San Joaquin Valley in the Diablo Range. Soils in the watershed are derived predominantly from marine sediments (sandstones and shales) of the Moreno, Kreyenhagen, and Panoche Formations, and Franciscan Assemblage. These soils support a sparse vegetative cover on most hillsides, with more vegetative cover generally associated with flatter valley floor areas and hillslopes at higher elevations. Large areas of unvegetated soils exist where the soil is thin, particularly on steep slopes and near stream channels. Areas of thin soil also occur over rock containing relatively high concentrations of selenium. Within the watershed upstream of I-5, approximately 30 percent of the land is managed by the U.S. Bureau of Land Management (BLM), primarily for green-season grazing. Other lands are privately held and used for rangeland grazing or irrigated cropland (just upstream of I-5). Downstream of I-5, lands are used primarily as agricultural cropland.

The PSCW lies within a semi-arid region, with precipitation occurring mainly between November and March. The following approximate average annual precipitation values have been reported for the watershed (DWR, 1981): 15 inches (Idria station) in the southern, higher elevation portion of the watershed (approximately 4,000 feet elevation); 8 to 10 inches (Panoche and Panoche 2SW stations) in Panoche Valley in the central portion of the watershed (1,200 to 1,300 feet elevation); and 7 inches (Mendota Murietta Ranch station) directly southeast of the watershed in the San Joaquin Valley cropland area (approximately 400 feet elevation). Based on this information, the average annual precipitation for the watershed is approximately 8 to 10 inches. Rainfall events yield erosion and the downslope and downstream transport of sediment. During these runoff events, sediment-loading problems occur in downstream agricultural production areas, Mendota urban areas, irrigation water conveyance structures, and streams. High concentrations of selenium are contained within this sediment. The Panoche alluvial fan is the principal source of selenium from the PSCW to the Grasslands watershed water bodies and the San Joaquin River.

A Coordinated Resource Management and Planning group (CRMP) was formed in 1989 for the PSCW. A CRMP goal is to foster a balance of existing land use practices and to develop reasonable management strategies to reduce future water quality impacts associated with flooding. The CRMP consists of residents of Mendota; ranchers and farmers; local resource conservation district personnel; drainage district personnel; water district personnel; representatives of local, state, and federal agencies; and local, state, and federal elected officials. The CRMP identified the need for an erosion/sediment study to identify and quantify point sources and source areas, and to recommend best management practices (BMPs) for reducing sediment loads.

The following objectives were applied to the overall PSCW assessment work:

(1) Assess the rate of soil erosion from the PSCW, and identify influencing factors such as land use (agriculture, grazing, etc.) and natural processes;

(2) Identify and rank high erosion source areas;

(3) Evaluate the magnitude of sediment delivery into the lower fan area, in the reach of Panoche Creek between I-5 and the California Aqueduct; and

(4) Develop and evaluate the effectiveness of BMPs for management of sediment production and reduction of sediment loads.

To conduct this assessment, three levels of detail and study effort were identified: (1) *watershed area*; (2) *study area*; and (3) *channel incision area*. The *watershed area* includes all areas of surface drainage into Panoche Creek or Silver Creek, upstream of I-5, covering a total of approximately 300 square miles. For purposes of this assessment, the watershed was subdivided into two general components - the upper and lower watershed (Figure 1). Included within the lower watershed are the detailed *study area* and a portion of the *channel incision area* (Figure 1), each delineated to facilitate in-depth study for this project. The *study area* consists of an approximately 30-square-mile area, within which the confluence of Panoche Creek and Silver Creek is located. Several large outcrops of selenium-bearing rock formations exist in this area, including the Moreno and Kreyenhagen Formations. Also, heavy grazing has occurred in the *study area* in the past, with some areas of heavy grazing still occurring. For purposes of this project, a *channel incision area* was delineated. The *channel incision area* extends approximately 7 miles downstream from the Panoche Creek/Silver Creek confluence, including a 2- to 3-mile reach downstream of I-5. Changes in cross-sectional geometry for the stream channel/floodplain in the *channel incision area* have been observed as the result of flood events, with many areas of significant erosion and/or deposition. Unstable streambanks also exist in other portions of the lower and upper watershed.

Erosion within the PSCW occurs in the following general temporal and spatial steps: (1) weathering of bedrock to form soil; (2) detachment and transport of soil via interrill (sheet) and rill erosion down hillslopes; (3) bulk transport from landslide and gully/channel areas; (4) detachment, transport and storage of sediment throughout the channel network; and (5) yield of transported sediment load at the watershed outlet (Panoche Creek channel at I-5 for this assessment work). During runoff events, areas with high potential for erosion can produce large loads of sediment to downstream areas. Such source areas include hillslopes, streambanks and streambeds. Therefore, evaluation of erosion processes for these types of features is emphasized.

3.0 LITERATURE REVIEW AND PRELIMINARY ANALYSIS

Literature and data from previous studies in the watershed and surrounding area were obtained and reviewed for the PSCW assessment work. Relevant literature and data included aerial photographs, previous reports, stream gaging data, and digitized mapping information. A synopsis of documents related to the PSCW was obtained from the Natural Resources Conservation Service (NRCS) office in Davis (NRCS, 1997a), and was used as a starting point for the literature review. A brief description of literature and data relevant to the PSCW assessment is provided below, according to type. This is followed by a summary of previous findings as applied to the current assessment work.

<u>Aerial Photographs</u>

Primary sources for aerial photos included the U.S. Bureau of Land Management (BLM), NRCS and California State University - Fresno (Fresno State). In coordination with field work, aerial photos were used primarily to assess stream channel geomorphic change. Table 1 lists aerial photographs that were reviewed as part of the PSCW assessment work.

<u>Reports and Related Work</u>

Various studies addressing key aspects of the PSCW have been conducted and reports developed, many since the 1970s. Reports and previous work in the PSCW have generally addressed flood control issues, natural resources, hydrology, and water quality. Flood studies were used to characterize hydraulic response of the Panoche/Silver Creek watershed (Boyle, 1992a), and were conducted as the result of observed flooding and related damage to agricultural cropland and residential areas. Recently, the U.S. Army Corps of Engineers (COE) presented a reconnaissance study on the hydrology of the PSCW (COE, 1994). The U.S. Fish and Wildlife Service (FWS) also provided a flood control reconnaissance study (FWS, 1995).

Studies of natural resources were conducted as part of the advance of 20th century agriculture in the San Joaquin Valley, and included a Soil Conservation Service (SCS) soil survey for the Mendota area (SCS, 1956). Other SCS (now NRCS) reports and publications included the San Benito County soil survey (SCS, 1969); Fresno County soil survey (NRCS, 1997b); and the Inventory of Resources in the PSCW (SCS, 1993). The Hydrologic Unit Planning Team Report - Westside Stream Group PSCW (SCS, 1994) provided a summary of the water quality, erosion, sediment, and flooding problems in the PSCW, along with preliminary steps to help identify solutions and strategies for implementation. The evaluation process included an assessment of the problems of concern.

As one of the major landowners in the PSCW, the BLM has developed plans for implementation of public use of their lands. The BLM Panoche Hills Management Plan - Draft EA (BLM, 1981) is one document in which range management and utilization are addressed. Another document, with application to the PSCW, deals with rangeland health standards and guidelines for California and northwestern Nevada (BLM, 1998).

Geologic surveys and studies have been performed over the years, including an early study on alluvial fan geomorphology by Bull (1960, 1964a,b). Some of Bull's research utilized 1850s vintage topographic maps; more recent (1950s) topographic maps have also been developed by the USGS. Lettis (1982) studied the Quaternary geology and structural history of the region, including part of the PSCW, and developed a geologic map. Recently, Bartow (1996) developed a geologic map which included primarily the lower watershed portion of the PSCW.

Other studies from which information was obtained for the current assessment work include: Archaeological Report (stratigraphy) (Meyer, 1997); Arroyo Pasajero reports (Northwest Hydraulics Consultants, Inc., 1996); and a series of studies performed by Boyle Engineering Corporation (Boyle) under contract to the U.S. Bureau of Reclamation and the Silver Creek Task Force. The work by Boyle, which was utilized in the current assessment work, included Evaluation of General Resource Conditions (Boyle, 1991); Development and Application of Hydraulic Model (Boyle, 1992a); and Development and Application of Hydrologic Model (Boyle, 1992b).

As a part of the CRMP process, a report was prepared by Summers Engineering, Inc. in May 1998 "...to summarize the historic Panoche/Silver Creek flooding problems, review the long-term watershed management options proposed by the CRMP team, recommend a flood control proposal to minimize the flooding impacts, and develop a preliminary estimate of cost for the flood control proposal" (Summers Engineering, Inc., 1998).

<u>Digitized Mapping Information</u>

Digitized mapping information was used to delineate the watershed boundary and to develop the database which contains the various attributes of the land surface, including topography, roads, and streams. This information was obtained primarily from the BLM. Observations from the erosion feature inventory also were entered into the geographic information system (GIS) database. Vegetation mapping information for the PSCW area was obtained from the internet website at University of California, Santa Barbara (UCSB, 1997), as developed for the "Gap Analysis Program" (GAP), and is presented in Figure 2. A listing of GIS coverages utilized for the current assessment work is provided in Appendix C.

In addition to digitized data imported from various outside sources, several layers of data were developed for the hydrologic characterization of the watershed. Hydrologic basin-specific delineations (sub-basins) were digitized from Boyle (1992b) and incorporated into the GIS. A total of 40 sub-basins from Boyle (1992b) were delineated, and additional subdivisions were made for sub-basins in the lower watershed for the current assessment, to yield a total of 49 sub-basins. These delineations were then used to spatially define the hydrologic and soil erosion parameters for non-point source modeling of sediment movement in the watershed, as described in Sections 4.4 and 5.1.2.

3.1 Watershed-Level Characteristics

The Panoche/Silver Creek Watershed (PSCW) is characterized by a wide range of geologic, soil, climatic, vegetative, and flood-related conditions and phenomena. While land use throughout the watershed is primarily for range, other land uses include a mercury mine at Idria and some irrigated cropland just upstream of I-5. Irrigated cropland continues downstream from I-5 as part of the larger San Joaquin Valley agricultural production area.

Geology and Soils

The PSCW extends from the San Joaquin Valley up into the east-central portion of the Coast Ranges, commonly known as the central Diablo Range. The geology consists mainly of marine and non-marine sedimentary rocks, including shale, sandstone, and conglomerate (BLM, 1981; Bartow, 1996). The *study area* has outcrops of Mesozoic and Cenozoic strata of the Diablo Range (Bartow, 1996). Rock outcrops have a wide range of competence and resistance to erosion, with high susceptibility to natural erosion processes in many portions of the watershed, especially in the lower watershed and the Silver Creek drainage. The Moreno and Kreyenhagen marine shale formations are exposed at various locations in the PSCW, and contribute to the occurrence of selenium and other trace elements. These exposed formations are prevalent in the confluence area, extending through the Silver Creek drainage from the eastern Panoche Hills through the western portion of Tumey Hills, and also in the southern portion of the watershed (Bartow, 1996 and Boyle, 1991).

Soils have been mapped as part of the San Benito County Soil Survey (SCS, 1969) and the preliminary Fresno County survey (NRCS, 1997b). The San Benito County survey addresses the upper watershed (Figure 1), and the Fresno County survey covers the *study area* including the confluence of Panoche and Silver Creeks. Predominant soils include: Kettleman (loam, well drained, moderately deep); Badlands (weathered, soft rock, shallow, highly erosive); Rock Outcrop; Xerorthents (variable texture, well drained, shallow to deep); Sedimentary Rock Land; Los Banos (clay loam, well drained, moderately deep); Panoche (loam, well drained, moderately deep); and Vallecitos (loam, well drained, shallow to moderately deep). General soil textures include clay, clay loam, silty clay loam, sandy loam, gravelly loam, and loam, or a variable (unmappable) mixture of textures within a given area typically occurring in valley floor portions of the lower watershed and also in the Tumey Hills area.

An interim report on resources in the PSCW (SCS, 1993) provides a review of selenium-bearing soils (Fresno County) and highly erosive soils (entire watershed). In this review, map units 680 (Torriorthents, stratified-Badland complex) and 717 (Belgarra-Torriorthents, stratified-Badland association) were shown as the soils contributing the most selenium in the lower watershed; the Badland component of these soils is "mostly seleniferous". In the upper watershed, Badland and Sedimentary Rock Land soils were inferred (unconfirmed) as potentially significant contributors of selenium, based on review of locations of selenium-bearing shale outcrops.

Climate

The PSCW lies within a semi-arid region. Climatic conditions in the PSCW vary according to elevation and location, with areas of higher elevation near the western edge of the watershed being cooler and wetter compared to lower elevation areas in the eastern portion of the watershed, including the *study area*. Precipitation occurs almost exclusively from November through March or April of each year in the form of rainfall in most areas of the watershed, with occasional light snow in the upper elevations near Idria. Historical precipitation data have been collected in the Panoche Valley and, more recently, measurements have been made continuously at the Panoche Road (near I-5) and Idria precipitation stations (Figure 1). The following approximate average annual precipitation values have been reported for the watershed (DWR, 1981): 15 inches (Idria station) in the southern, higher elevation portion of the watershed (approximately 4,000 feet elevation); 8 to 10 inches (Panoche and Panoche 2SW stations) in Panoche Valley in the central portion of the watershed (1,200 to 1,300 feet elevation); and 7 inches (Mendota Murietta Ranch station) directly southeast of the watershed in the San Joaquin Valley cropland area (approximately 400 feet elevation). Based on this information, the average annual precipitation for the watershed is approximately 8 to 10 inches.

Watershed Vegetation

The PSCW is part of the San Joaquin Valley sub-region of the California Floristic Province (Hickman, 1993). Major upland vegetation types in the watershed include annual grasslands, and combinations of grassland with halfbrush, chapparal, oak, and woodland (Boyle, 1991). Annual grasslands are the predominant plant community throughout most of the watershed as shown in Figure 2 (UCSB, 1997); these are dominated by exotic annual grasses (*Bromus* spp., *Avena* spp., *Vulpia* spp.), exotic forbs (*Erodium* spp., *Trifolium* spp.) and native forbs (*Lupinus* spp., *Castilleja* spp.) (BLM, 1998 and BLM, 1981). Common shrub species include saltbush, allscale, or quailbush (*Atriplex* spp.). Plant community composition and production are highly variable from year to year, and are correlated with topographic location, seasonal temperature, and timing and amount of precipitation (Bartolome, et al., 1980; McNaughton, 1968; Pitt and Heady, 1978).

Flooding and Erosion

Two major streams drain the PSCW - Panoche Creek and Silver Creek (Figure 1). Silver Creek drains the southern portion of the watershed, and Panoche Creek drains the central, western, and northern portions of the watershed. Approximately two-thirds of the PSCW is drained by Panoche Creek, and the other one-third by Silver Creek. These two creeks join to form Panoche Creek approximately 4 to 5 miles upstream of I-5. As described above, this confluence is located within the PSCW assessment *study area* and coincides with the upstream end of the *channel incision area*.

A summary of historical events in the western San Joaquin Valley is presented in Figure 3. Within the PSCW, streamflow was measured by the USGS during several periods, beginning with measurement of annual flow in 1922-1923; monitoring at a gaging station just downstream of the confluence of Panoche and Silver Creeks from 1950 to 1953; monitoring at the same station from 1959 to 1973; and monitoring of Panoche Creek at the I-5 bridge from December 1997 to present. Several flood frequency analyses have been performed for Panoche Creek, downstream of the confluence, as summarized by Boyle (1992b). In addition, the COE (1994) developed a flood frequency analysis for Panoche Creek downstream of the confluence. The ranges and averages of peak flood flow rates based on results of these studies are listed in Table 2. The wide ranges in predicted flood flow peak discharges can be attributed to different skew values used in the flood frequency analyses, along with differences in the data sets used. In some cases, one estimate may have included potentially questionable flow measurements which another study excluded.

Historical flood damage in the PSCW (including areas downstream of I-5) has been extensive, and recent increases in flood damage have been related to (SCS, 1994): (1) increased peak and annual stream flows; or (2) changes in channel plan form downstream of I-5. Increased peak and annual stream flows were attributed to a decrease in vegetation for areas upstream of I-5, improperly managed farming and livestock grazing activities in the lower watershed, and soil compaction (SCS, 1994). Downstream of I-5, watershed influences on flood damage included a decrease in channel capacity, channel realignment, sediment deposition in channel, and incomplete flood control works.

During major rainfall/flood events, heavy runoff and significant erosion are evident, especially in the lower watershed and in the Silver Creek drainage, upstream of the confluence. Previous studies (such as Boyle, 1991) have identified natural erosion processes occurring in the watershed, including gully and sheet erosion, natural landslides, and streambank sloughing. Accelerated erosion occurs readily from naturally erosive hillslopes, especially in the lower watershed as also affected by grazing practices, in the form of interrill, rill, and gully erosion. Interrill (or sheet) erosion is the primary means by which soil is removed from highly erodible hillslopes, which typically have thin soils and a low percentage of vegetative cover. Interrill erosion advances to form rill erosion and, upon additional concentration of flow and downslope distance, rills can form gullies. Gully erosion may also form as the direct result of concentration of flow on cattle trails or in areas of runoff from roads.

Streambank sloughing occurs naturally and also as the result of livestock grazing within and adjacent to stream channels. Streambank failure can occur as a consequence of the undercutting by flowing water, saturation of streambank soils, and/or the absence of full vegetative cover in the streambank/riparian zone. Erosion of streambanks occurs throughout the PSCW where defined channels are located, with less frequent occurrences in upstream portions of the Panoche Creek drainage. A summary of previous work related to processes occurring in the *channel incision area* is provided in Section 3.3.

Land Subsidence

Land subsidence due to groundwater withdrawal has occurred primarily in the area downstream of the *study area*. The magnitude and rates of land subsidence through the end of 1982 are documented in several reports prepared by the USGS (Poland, et al., 1975; Ireland, et al., 1984; and Ireland, 1986). Bull (1964a) also addressed land subsidence in the alluvial fan area. These reports show that over 29 feet of subsidence occurred at a location near Panoche Creek and the California Aqueduct. This location experienced the maximum known land subsidence due to groundwater withdrawals in the San Joaquin Valley. The time period of greatest subsidence was generally from 1948 to 1969; during some years in this period, the annual rate of subsidence exceeded 1.5 feet per year. Groundwater withdrawals were mainly for irrigation of crops. Due to importation of irrigation water from the California Aqueduct starting in the late 1960's, groundwater levels began rising and land subsidence slowed. The surface extent of land subsidence extended southwestward to approximately the location of I-5 (Ireland, 1986).

It is possible that the magnitude of historical land subsidence downstream of the *study area* has disturbed the dynamic equilibrium of the watershed. The abrupt (in a geomorphic sense) lowering of the downstream reach of Panoche Creek could have affected the channel geomorphology for miles upstream of the subsiding area. Although land subsidence during its approximately 20-year maximum period occurred fairly continuously, the response of the Panoche Creek channel would be episodic, occurring mainly during large runoff events. Therefore, the effects of historical land subsidence on the Panoche Creek channel upstream of I-5 could lag behind the approximately 20-year period of maximum subsidence. It also is possible that subsidence is responsible for recent aggradation observed in the reach of Panoche Creek downstream of I-5. However, the data needed to distinguish the role of land subsidence from the contributions of other factors that contribute to geomorphic change in the PSCW are generally not available.

3.2 Study Area Erosion Sources

Bartow (1996) identified locations of major landslides in a portion of the lower watershed, as part of a geologic map of the area. No other previous work, related to identifying, documenting, and mapping erosion features, has been completed.

3.3 Channel Incision

Considerable incision and widening have been observed in the *channel incision area* over the past 130 years. Bull (1960, 1964b), in his studies of alluvial fans along the west side of the San Joaquin Valley, documented some of these changes by comparing 1854 topographic maps of the Panoche Creek channel with mapping that he conducted in the late 1950s. He found that by the late 1950s the Panoche Creek streambed was two to six times wider, the depth of incision had increased by as much as 25 feet, and the incised reach had migrated five miles farther downstream. Bull (1960, 1964b) concluded from examination of historical records of climate and land use that episodes of incision (Figure 3) coincided with periods of above normal annual and daily rainfall (e.g., 1876 to 1896 and 1935 to 1945). Therefore, Bull (1960) postulated that incision of the Panoche Creek alluvial fan occurred primarily during years of high stream flows. Other possible influences on geomorphic change mentioned by Bull (1960) and other researchers include tectonic uplift of the hills and land subsidence in the San Joaquin Valley.

Few previous studies have focused on the *channel incision area*, although reports have focused on certain aspects of the channel and watershed hydrology and hydraulics. For example, Boyle produced a series of reports that characterized the Panoche Creek watershed general resource conditions (1991), hydrology (1992b), and hydraulics (1992a). Of particular relevance to the *channel incision area* study, is a set of 1990 channel cross sections provided in Boyle's hydraulics report (1992a). A 1963 U.S. Bureau of Reclamation (USBR) study that focused on evaluating the engineering geologic conditions for a proposed dam in the vicinity of the 1960s era USGS gaging station included a detailed topographic map and description of the material properties of terrace sediment in the area of the proposed dam.

Multiple studies have been conducted over the past several decades to characterize the Arroyo Pasajero watershed, located south of the PSCW, including: Boyle (1989), DWR (1990, 1992), Munn, et al. (1981), NHC (1996), and Simons, Li & Associates (1985). These studies are relevant to this study because they provide a baseline comparison for estimates of watershed sediment yield and the relative contributions of different sediment delivery processes. Data from these previous studies are summarized in Section 3.4 of this report.

3.4 Previous Estimates of Sediment Yield

To put into context estimates of watershed sediment yield developed in this project, past evaluations of sediment yield from the Panoche Creek watershed, and from the Arroyo Hondo and Arroyo Pasajero watersheds to the south, were reviewed for the current assessment work. Although there have been multiple reports in which sediment and erosion problems of the Panoche Creek watershed were addressed, there have been few studies in which quantitative, watershed-specific data were collected and evaluated. The available sediment yield data from Panoche Creek are shown in Table 3, along with estimates of sediment yield for the Arroyo Pasajero and Arroyo Hondo alluvial fans made by NHC (1996) and Bull (1960), respectively. The Arroyo Pasajero watershed, despite being the closest large stream system with available data on sediment yield and transport, has watershed characteristics that differ from those of the PSCW. Arroyo Pasajero is a larger watershed, has greater topographic relief, and is underlain primarily by rocks of the Franciscan Assemblage.

Substantial effort has been devoted to understanding the Arroyo Pasajero stream system, which is approximately 40 miles south of Panoche Creek. In an unpublished study, Northwest Hydraulic Consultants, Inc. (NHC, 1996) estimated annual sediment yields for Los Gatos Creek and its major tributaries using the Modified Universal Soil Loss Equation (MUSLE) (Table 3). They also evaluated processes that deliver sediment to the mainstem channel and compiled previous Arroyo Pasajero studies. Based on MUSLE and geomorphic analyses, NHC (1996) estimated that 30 to 60 percent of the total sediment yield was derived from the upland watershed, 10 to 30 percent was derived from channel bank erosion, and 10 to 30 percent of the total yield was eroded from the channel bed. NHC (1996) summarized previous Arroyo Pasajero studies (Army Corps of Engineers, 1971; Munn, et al., 1981; Simons, Li & Associates, 1985; Boyle, 1989), which, as a group, estimated that from 38 to 70 percent of the sediment yield was derived from the upland watershed, 33 to 47 percent was derived from channel bank erosion, and -3 percent (aggradation) to 24 percent of the watershed's sediment yield was eroded from the channel bed. In a 1990 study of Arroyo Pasajero, the California Department of Water Resources (DWR) estimated that 30 percent of the total load was derived from erosion of the banks of the mainstem and large tributary channels. DWR (1990) also concluded that deposition of sediment on the channel bed was occurring, not erosion. In 1992, DWR released a report describing the results of sediment transport monitoring conducted in February and March of 1991, in which they showed that the suspended sediment load accounted for approximately 90 percent of the total load. Thus, according to DWR's calculations, bedload accounts for approximately 10 percent of the total load in the Arroyo Pasajero system. Boyle (1989) calculated upland sediment yields for many subbasins within the Arroyo Pasajero watershed using the MUSLE (Table 3) and also estimated that bedload composed from 19 to 36 percent of the total sediment load.

4.0 TECHNICAL APPROACH

The assessment of the PSCW included two parallel and linked analyses: upland erosion process evaluation by field inventory and non-point source modeling, and geomorphic channel analysis that included historical change evaluation. For assessment of soil movement, the following processes were evaluated through field data collection and literature review: rill and interrill hillslope soil loss; landslide potential; gully formation and advancement; stream course incision, erosion, and sediment detention and supply (within the *channel incision area*); and, as possible, effects from historical land subsidence caused by groundwater withdrawals. To identify high erosion source areas, the following activities were conducted: general mapping of the *watershed area*, field reconnaissance and inventory development for the *study area*, assessment of the dynamics and contribution of the *study area* relative to the watershed, and evaluation of the historical channel change in the *channel incision area*.

Results of the PSCW assessment are presented in Section 5.0. Evaluation of various BMPs for control of on-site erosion and downstream sediment delivery was accomplished through a combination of literature- and model-based assessments, as well as previous experience of the project team. Appropriateness of a BMP for a particular problem area included consideration of short- and long-term effectiveness, operation and maintenance requirements, and cost. The evaluation of BMPs is provided in Section 6.0.

4.1 Watershed Reconnaissance

After a preliminary review of literature and existing data, a field study was conducted to fill data gaps at the watershed level. This portion of the study included reconnaissance of the entire watershed, and detailed field surveying at specific lower watershed locations. Specific information developed from the reconnaissance included: land use; vegetative cover; and review of potential sediment sources, including streambanks in the upper watershed. Observations of the effects of grazing were noted. Estimates of hydrologic parameters related to characteristics of the watershed for modeling efforts were also developed through this field reconnaissance.

4.2 Study Area

An inventory of sediment sources was conducted in the *study area*. The *study area* inventory was conducted at a much more detailed level than the watershed reconnaissance, largely because of the expected increased influence of this area on sediment loading to downstream areas. *Study area* erosion features were characterized in terms of location, areal extent and potential erosion as observed in the field, along with incident and adjacent land use, and slope, aspect, and vegetative cover. Erosion features, and associated potential for additional erosion, were mapped and documented throughout the *study area*. Within the *study area*, and extending 2 to 3 miles downstream from I-5, the *channel incision area* was characterized and evaluated through additional field data collection activities, as described below.

4.3 Channel Incision Area

The purpose of the *channel incision area* study was to evaluate the factors and processes that most strongly influence the sediment budget within the *channel incision area* and, if possible, to estimate amounts and rates of sediment erosion, deposition and transport. The *channel incision area*, and reaches upstream and downstream, have experienced significant geomorphic change since the earliest human occupation of the area (Figure 3). In ephemeral streams such as Panoche Creek, geomorphic change usually occurs episodically, with long periods of relative stability followed by short pulses of rapid change. The large flows during the winter and spring of 1998 were particularly fortuitous for this study because they provided the opportunity to observe directly (or observe shortly after the large flows) the processes that occur in extreme flood years, when most geomorphic change occurs.

To evaluate channel stability and long-term geomorphic trends, an analysis of historical changes to the channel was performed by evaluating a variety of archival information. To obtain this information, historical societies and libraries known to catalog information from the area were contacted. This information was compiled and compared (Plates 1 and 2) to identify geomorphic trends (e.g., long-term incision or bank erosion) and characterize historical geomorphic changes to the stream system. Detailed mapping and documentation of current physical and biological conditions was also performed; estimates of historical watershed sediment yield were developed through a variety of techniques; and the influence of adjacent land uses on the production and movement of sediment through the *channel incision area* was evaluated.

The historical channel change analysis involved a review of archival data on prior channel plan form and pattern. Temporal variations in channel conditions were identified based on maps, aerial photographs, previous studies, and local sources. Reexamination of channel cross-sectional widths measured by Bull (1960) in the late 1950s, and first surveyed in 1854, was conducted to compare rates of change that took place from 1854 to the late 1950s with those that have taken place from the late 1950s to the present (Plate 1c). To further evaluate changes in channel plan form through time, locations of channel banks and thalwegs were compiled from multiple vintage topographic maps and aerial photographs (Plate 2). Topographic maps used those shown in Table 4. The 1950s era USGS maps were photo revised in 1971, so alteration of the channel associated with construction of I-5 was readily identifiable. Aerial photographs were selected from those listed in Table 3 based on: the scale of the photographs, the area covered by the photographs, the date of the photographs, and the quality of the prints. Using these criteria, 1937, 1982, 1990, and 1998 aerial photographs were selected to evaluate the historical change in channel plan form.

To evaluate changes in channel profile, longitudinal profiles were compiled from the topographic information shown in Table 4. Measurements of channel geometry from 1990 were obtained from Boyle Engineering Corporation (developed by Boyle, 1992a) and were used to develop the longitudinal profile (Plate 1a). Approximately 80 years of change are depicted by this profile.

As with many kinds of historical change analyses, registration of multiple vintage maps and aerial photographs is problematic. The most difficult task is correlating measured longitudinal profiles from maps. Measuring the sinuous path of the creek on maps of different vintage and scale developed using different cartographic approaches in an area of subsidence-related land-level change is inherently difficult. For the current assessment work, it was assumed that the vertical registration was consistent, and landmarks like bridges and gaging stations were used to ensure horizontal consistency. When horizontal registration was inconsistent between measured profiles, the profiles were stretched or compressed to achieve the most reasonable fit. However, the 1990 data appears to have been registered to a different vertical datum than the earlier surveys. The 1990 profile remains the most difficult to fit with other profiles; it depicts, for example, a channel significantly lower than was expected given observed field relations.

Channel conditions for the current assessment work were documented in May and June 1998, following the large winter and spring flows, by mapping, describing and photographing the effects of the large flows on the channel banks and bed (Plate 1). Areas of sediment deposition, bank erosion, and channel incision were identified. Areas of active bank erosion were relatively easy to identify when compared with identifying and characterizing channel incision. Upstream reaches in the *channel incision area* have a cross-sectional geometry consisting of steep, often near-vertical banks bounding a relatively flat sandy bed. In this setting, if the channel bed is covered with recently deposited sediment, and no vegetation in the channel bottom survived the large flows, it is difficult to evaluate incision/deposition without historical cross-sectional information. On Plate 1, measurements of bank height are provided, along with locations of deposition and bank and/or thalweg erosion. Also included on Plate 1 are photographs of the *channel incision area*.

To evaluate changes in channel cross-sectional form, 15 cross sections were surveyed using an electronic total station. The surveyed cross sections were sited to closely match the locations of cross sections measured in 1990. Cross sections for which there were problems in resurveying the exact site of the 1990 measurements included cross sections 36, 40, 55, and 56. Plots of the 1990 and 1998 cross sections are shown on Plate 1 and in Appendix D.

To estimate the total suspended sediment load transported past the I-5 USGS gage between January and April 1998, preliminary USGS gaging and suspended sediment data for the 1998 water year were utilized (USGS, 1998). Using these data, rating curves and regression relationships were developed, an hourly time-step model of suspended sediment transport was computed, and the total sediment load moved each day during the January to April 1998 period was tabulated. These calculations are described in more detail in Section 5.3.4.

4.4 Erosion Modeling

In combination with the watershed erosion inventory and detailed *study area* and *channel incision area* assessments described above, the effects of various landscape characteristics on erosion processes and sediment delivery were evaluated through modeling. This modeling was conducted on a watershed scale, with more detail incorporated in the *study area*. Many empirical models have been developed to assess erosion processes, including the Universal Soil Loss Equation (USLE), the Revised USLE (RUSLE), the Modified USLE (MUSLE), and the Agricultural Non-point Source Pollution Model (AGNPS). Of these, AGNPS was utilized for modeling because of its ability to handle three basic watershed components of interest in this assessment work: hydrology, erosion, and sediment transport (Young, et al., 1987). Since its original development in the 1980s by the U.S. Department of Agriculture - Agricultural Research Service, numerous improvements, revisions, and updates have been made to AGNPS; Version 5.00 (the latest version, released in May 1995) was utilized for the PSCW assessment work.

AGNPS was applied in the manner for which it was designed, that is to facilitate: (1) critical area identification; and (2) BMP assessment and selection. AGNPS is also intended for general use in development of comprehensive sediment control plans. Model components utilize equations and algorithms that are well established and have been widely used by organizations such as the NRCS. The hydrologic component of the model utilizes the SCS Curve Number approach, and the erosional component utilizes the USLE. These methods were applied to predict runoff and erosion for individual subdivisions or cells. The cells were delineated to account for spatial variability of hydrologic and erosional parameters throughout the watershed. According to the requirements of AGNPS, each cell subdivision had 22 items of input information, including: runoff curve number, land slope, channel slope, soil erodibility factor, and soil texture. Surface water flows and sediment loads are routed through the cells, according to definition of flow direction for each cell. Output includes total runoff, sediment load (delivery), sediment particle size distribution, and combined interrill and rill erosion from upland areas; this output can be obtained for the watershed outlet (i.e., *study area* boundary) and at intermediate locations.

Input parameters for each cell of the model were developed from previous studies and field observations from the current study, and are presented in Appendix A. The following listing provides a summary of types of input parameters and sources for each: soil texture (SCS, 1969 and NRCS, 1997b); soil erodibility factor (NRCS, 1997b, and USLE soil texture relations and equations); cover and management factor (field observations, USLE literature); erosion control support practice factor (USLE literature); runoff curve number (Boyle, 1992b); land slope, shape, and slope length (GIS program analysis); type of channel, channel bed slope, and side slope (field observations, GIS program analysis); channel Manning's roughness coefficient (field observations, open channel flow literature); surface condition (field observations, AGNPS guidance); aspect of drainage path (GIS program analysis); and impoundment characteristics (AGNPS guidance). For analysis in AGNPS, the watershed was subdivided into approximately 4800 40-acre square cells to represent the 300-square-mile drainage upstream of I-5. A 40-acre cell size for all parts of the watershed was selected for the following reasons: (1) a larger cell size would overgeneralize conditions in some parts of the watershed, especially in the complex topography and land surface conditions of the *study area*; (2) a smaller cell size would not add relevant detail to the model, given the scope of the reconnaissance-level field work for developing model input parameters; and (3) this cell size can be conceptualized and easily related to USGS topographic mapping scales. Subdivision of the watershed, and associated assignment of input parameters for each cell, was accomplished through analysis in GIS using ARC/INFO software.

The major precipitation event which occurred on February 2 and 3, 1998 was analyzed based on rainfall data collected at the Panoche Road and Idria continuous monitoring stations (DWR, 1998). This event had a duration of approximately 24 hours, and yielded a maximum peak flow rate of 8,400 (Moore, 1998) to 10,000 cubic feet per second (cfs) (USGS, 1998) at the Panoche Creek/I-5 USGS gaging station. The USGS also collected suspended sediment samples from the creek during this event. Because of the abundance of measured data for this event, additional analyses were performed to calibrate precipitation input for the AGNPS model (for a 24-hour event), and the preliminary streamflow/sediment data were also compiled to enable a comparison of measured and modeled outflow at the watershed outlet (I-5) for this event. Evaluation of the precipitation, streamflow, and sediment loading data, which correspond with the February 2-3, 1998 precipitation event, is presented in Section 5.1.2. The 24-hour duration storm was used only for comparison of measured and modeled conditions. Additional analyses for existing and BMP-influenced conditions utilized the 48-hour storm as discussed below.

Results of modeling for existing watershed conditions were used to develop an erosion hazard rating (EHR) map in which the watershed is delineated into the following ranges of erosion rate for a 100-year, 48-hour storm: low EHR (0-10 tons/ac), moderate EHR (10-20 tons/ac), high EHR (20 -30 tons/ac), and extreme EHR (greater than 30 tons/ac). Section 5.1.2 provides the results from the AGNPS modeling for existing conditions in the PSCW. The 100-year, 48-hour storm was selected for modeling existing conditions because this storm duration was used in the HEC-1 model (obtained from the NRCS and developed previously) which was applied to evaluate one of the BMP scenarios (see Section 6.2). To maintain consistency, the 100-year, 48-hour storm was also used as the basis for simulating the effects of other BMP scenarios using the AGNPS model. Assessment included evaluation of the potential effects of changes in input sediment delivery, because of BMPs, to flow rate and sediment transport at the watershed outlet and then to downstream areas.

5.0 RESULTS

Results for the current PSCW assessment work are presented and discussed in this section. Information from previous studies was utilized to characterize existing conditions and to document historical changes and trends. The overall objective of the field work was to fill data gaps identified during the literature review, including development of an up-to-date characterization of *watershed area*, *study area*, and *channel incision area* conditions. Field work also provided verification of previous data, along with development of new data, for input into the AGNPS model. The following discussion provides a summary of results from the *watershed area*, *study area*, and *channel incision area* investigations.

5.1 Watershed Reconnaissance

Field reconnaissance in the *watershed area* was performed in February and April 1998. Previous studies also were reviewed for development of an appropriate overview of land use and hydrologic conditions. One of the main purposes of the watershed reconnaissance and literature review was to develop an understanding of the differences in land use, vegetative cover, and hydrology between the upper and lower areas of the watershed. This information was then used to develop the required input parameters for the AGNPS model and, subsequently, to provide an overall assessment of the current watershed condition and predicted conditions resulting from implementation of watershed-level BMPs (see Section 6.0).

5.1.1 Land Use and Cover

Land use within the PSCW is predominantly a combination of green-season grazing and wildlife habitat. A small amount of cultivated cropland, relative to the entire watershed area, is located at the downstream end of the watershed, just upstream of I-5. Approximately 30 to 35 percent of the watershed is owned and managed by the BLM, with the remainder primarily in private holdings. Several mines have operated in the area, but none are currently active. Mercury mining has occurred at Idria, and seepage from this area continually provides a potential contaminant source to surface water runoff (Boyle, 1991). Gravel mining has occurred at several points along the stream.

Reconnaissance observations of land use and vegetative cover were made in February 1998, for the upper watershed, and in April 1998 for the upper and lower watershed areas. This information was used to evaluate vegetation characteristics and range management in the *study area* (see Section 5.2.1), and in the upper watershed (discussed below). Also, observations were combined with data gleaned from the literature to develop input to model the hydrologic and erosional response of the watershed (see Section 5.1.2). The following discussion summarizes observations, in many cases providing comparisons of upper and lower watershed areas.

In general, grazing pressure in the upper watershed is much less than in grazed areas of the lower watershed. Exceptions to this were noted in the Vallecitos area, near the confluence of San Carlos and Larious Creeks to form Silver Creek, where the upland, riparian, and some channel areas appear to be grazed heavily. All other parts of the upper watershed appear to be less impacted from grazing than in the lower watershed. The south end of Panoche Hills within the *study area* did not appear to be grazed heavily. Fencing in many upland areas serves to exclude or manage utilization by livestock. Eroded hillslopes generally coincided with intense cattle trailing and hoof activity, especially in the lower watershed. Most other upper watershed areas with erosional features were limited to streambanks along Silver Creek and its tributaries, as well as in Panoche Creek generally downstream from its confluence with Griswold Creek. Streambanks which appeared to be susceptible to sloughing were associated with areas of deep channel incision. The Panoche Creek channel and streambanks appear to be less disturbed with increasing distance upstream from the confluence, although incision and related streambank erosion are still evident upstream to its confluence with Griswold Creek.

The riparian zone in the upper watershed was generally well vegetated with annual grasses and dryland shrubs except in areas of heavy grazing as noted above. Riparian zone vegetation in the upper watershed was more prevalent than the almost non-existent riparian vegetation in the lower watershed. Upland pastures in the upper watershed were generally well vegetated, in excellent condition, while lower watershed pasture conditions varied widely, from excellent on selected upper slope areas to poor in many drainages. South-facing slopes in the lower watershed areas typically were partially to fully dominated by red brome (*Bromus madritensis* ssp.*rubens*), while north-facing slopes tended to support a greater diversity of plant species. In some areas of the lower watershed, such as in Panoche Hills, ungrazed barren slopes indicate an influence from geology and soils, and not an effect of grazing intensity or pressure. North-facing slopes generally support a more diverse mixture of species than south-facing slopes. The watershed sub-area with the greatest impact from grazing is along Silver Creek in the lower watershed, where a large amount of trampling was observed on streambanks, along with heavy trailing and little to no grass cover. A large extent of saltcedar (*Tamarix* spp.) invasion along Silver Creek was also observed.

5.1.2 Hydrologic and Erosion Modeling

The AGNPS model was applied to the watershed to simulate hydrologic and erosion processes. While AGNPS is an empirical model, and is not process-based, the results are best applied to the evaluation of change from existing to future conditions in which BMPs have been implemented. This is the purpose for which the model was developed; it is not intended to be used for absolute predictions of flow and sediment yield. AGNPS has been developed and tested as a single-storm event model, and is used as such in this assessment work, relying on a SCS cumulative precipitation distribution selected according to region of the U.S. The distribution for the current work is the so-called "Type I" distribution, which applies to the Coastal Ranges of California within which the PSCW is located. For these evaluations, the primary location of interest in the watershed is at the outlet (I-5). The output variables for comparison at this location include peak flow rate, total runoff volume, and total sediment yield.

Major assumptions for application of AGNPS to the PSCW include: (1) the model is appropriate given the unique combination of geology, soils, and land use; (2) the SCS curve number approach provides an acceptable representation of the rainfall/runoff processes; and (3) the USLE provides an acceptable representation of hillslope erosional processes. Also, a single value of rainfall depth was used to represent precipitation over the entire watershed, although average annual precipitation is known to range from approximately 7 to 15 inches. The AGNPS model assumes that sediment loading results from non-point interrill, rill, streambed, and streambank erosion. Interrill and rill erosion are predicted as a combined amount. Point sources such as gully and landslide erosion are known to occur in the watershed and, while AGNPS allows manual input of these other sources into the model as additional erosion sources, contributions from each of these sources are not readily quantifiable for an individual storm. Therefore, these additional sources were not included in the model input. Streambank and streambed erosion are expected to be underpredicted by the model because of the highly dynamic nature of these processes in Panoche and Silver Creeks. The analysis of existing conditions included the effect of the dense, ungrazed vegetation near the confluence of Panoche and Silver Creeks, between the stream channel and the highly erodible hillslopes to the southeast and east of this area (with no observed transport pathway to the creek channel for eroded hillslope materials). A summary of input parameters applied to AGNPS is provided in Appendix A.

Despite the limitations related to using the AGNPS model, as noted above, this model was selected because of its capability for comparison of existing conditions with future conditions after implementation of BMPs. This use of the model is consistent with the guidance provided by the AGNPS developers (see Section 4.4), and the relative results of such comparisons should be reasonable. The unique geology and soils, however, combined with the empiricism of the USLE and SCS curve number approach, may yield inaccurate absolute predictions of sediment yield and runoff by AGNPS.

Analysis of Measured Data, 24-Hour Storm

Rainfall, runoff, and sediment concentration data collected during and immediately after the February 2-3, 1998 rainfall event, which was the largest rainfall/runoff event in the 1998 winter/spring period, were analyzed for subsequent comparison with AGNPS model predictions of runoff and sediment yield for the 24-hour storm. Comparison of measured and modeled peak flow rate was desired to ensure model simulation as close as possible to the maximum flow rate of the measured event. Preliminary DWR precipitation data (Panoche Road and Idria) and USGS stream flow and sediment data (Panoche Creek/I-5) used in this analysis are included in Appendix B.

Figure 4 presents a comparison of the generic 24-hour SCS Type I distribution and cumulative measured depths from 0700 hours, February 2 to 0700 hours, February 3 for the Panoche Road and Idria precipitation stations. Measured precipitation for the 24-hour storm at Idria (3.6 inches) was substantially greater than the measured amount at Panoche Road (0.76 inch), primarily because of the difference in elevation and storm distribution over the area.

Figure 5 presents USGS measurements of runoff generated at the watershed outlet (i.e., at I-5 bridge) for the period from February 2-5, 1998. The hourly runoff gage height and rating curve data for the USGS I-5 gaging station (#11255575) were obtained directly from the USGS - Sacramento office (USGS, 1998), and are preliminary. Sediment measurements were also made by the USGS in 1998, and preliminary data are also included in this analysis. The measured peak flow rate during this period was 10,000 cfs, as based on a corrected (but still preliminary) rating provided by the USGS in late June 1998. An estimate of 8,400 cfs was also provided (Moore, 1998). Therefore, the peak flow rate for this event was assumed to be within the range of 8,400 to 10,000 cfs. The measured total volume of runoff for the watershed was approximately 8,200 acre-feet, or 0.52 inch (based on watershed surface area). Combining runoff volume with measured sediment concentration data provides an estimate of approximately 1.86 million tons total sediment yield resulting from this storm.

Output from AGNPS for Existing Conditions, 24-Hour Storm

The following discussion of AGNPS model output focuses on results at the watershed outlet for existing conditions, and includes a comparison with measured data from the February 2-3, 1998 storm event. The measured data were adjusted to develop an average watershed precipitation depth for the February 2-3, 1998 storm, because AGNPS requires uniform rainfall over the watershed as input to the model. Use of an average precipitation depth for the watershed is expected to place more emphasis on sources and runoff from the lower elevations and less on the higher elevations. However, there is not sufficient information to state if the results from AGNPS are over-estimates and, if so, by how much, although erosion sources in the lower watershed are expected to be over-estimated and runoff sources in the upper watershed to be under-estimated based on this approach.

To develop a uniform rainfall depth for input to AGNPS, the storm event precipitation depths were assumed to be distributed similar to the average annual precipitation, with the 3.6 inches measured at Idria adjusted as based on the iso-precipitation lines for the watershed presented by Boyle (1992b), yielding a watershed average storm depth of 2.3 inches. This 24-hour storm precipitation depth was input into AGNPS to develop a comparison of measured and modeled peak runoff rate and sediment yield for the February 2-5, 1998 runoff event.

The soil moisture condition (i.e., antecedent moisture) prior to the February 2-3, 1998 rainfall event was assumed to be wetter than normal because of some light rains in the previous week. Therefore, the curve numbers representing wet conditions were applied to each sub-basin. To compare the peak flow rate predicted by the AGNPS model at the watershed outlet, relative to the measured February 2-5, 1998 runoff event, the lower and upper limits of 24-hour precipitation depth were set at 2.0 and 5.0 inches, respectively (Table 5). The simulated peak flow rate of 9,090 cfs (for a precipitation depth of 2.3 inches) was the closest to the average of measured peak flow rate which were unofficially reported as 8,400 (Moore, 1998) and 10,000 cfs (USGS, 1998). Therefore, a 24-hour precipitation depth of 2.3 inches yields an acceptable estimate of peak flow rate at the watershed outlet for the February 2-3 storm. The AGNPS model overpredicted total runoff volume from the watershed at 1.25 inches, compared with the measured 0.52 inches.

Total sediment yield predicted by AGNPS (13,120 tons) was much less than the measured sediment load (1.86 million tons) because of the highly dynamic nature of the Panoche and Silver Creek channels, and associated large streambank and streambed erosion components. This observation, along with geomorphic analyses (see Section 5.3), suggests that the AGNPS model does not provide a reliable simulation of the magnitude of streambank and streambed erosion. However, the selected model simulation is viewed as a reasonable representation of watershed flow rate conditions and upland erosion source areas because the peak flow rate from the watershed would be essentially unchanged by the presence of a large, unmodeled sediment contribution from streambanks and streambeds.

Based on the results of the modeling, field observations of upland erosion features, measured sediment load data, and evaluations regarding channel erosion, the overall contribution of sediment from upland erosion features is very minor relative to the total sediment load. The principal source of sediment transported to the lower Panoche Creek fan results from streambank and streambed erosion. This source accounts for the majority of sediment yield from the watershed, with much of this erosion occurring near the confluence of Panoche Creek and Silver Creek (see Section 5.3).

<u>Erosion Hazard Rating Map, 48-Hour Storm</u>

Using the AGNPS input files for existing conditions, and changing the precipitation depth and duration to a 100-year, 48-hour storm event to maintain consistency with subsequent model evaluations of several BMP scenarios (see Section 6.2), an erosion hazard rating (EHR) map was developed for the watershed, as shown in Figure 6. This figure shows upland erosion rates (tons/acre) for each individual cell of the watershed, resulting from a 48-hour storm which would produce an approximately 100-year return period peak runoff rate. Natural erosion processes, occurring on naturally susceptible hillslopes with steep slopes and sparse vegetative cover, are the primary influences resulting in erosion rates greater than 20 tons/acre (for this storm) in Griswold Canyon, the hills near Idria, and the lower Panoche Hills west and north of the confluence area. The northern Tumey Hills area also appears to be naturally susceptible to erosion, but there is an apparent additional influence of range utilization in this area, where erosion rates greater than 20 tons/acre are predicted. Figure 7 depicts the total sediment yield for each cell, from the same (100-year, 48-hour) storm, as affected by input from the next-upstream cell, erosion within the cell, and transport to the next-downstream cell. This figure shows the expected trend of increasing sediment yield with downstream distance, which implies that sediment is being transported through the stream reaches upstream of I-5.

5.1.3 Long-Term Sediment Delivery from the PSCW

As a baseline for comparison with other estimates of sediment yield, the long-term sediment yield of the Panoche Creek watershed was calculated using an estimated volume of Holocene (11,000 years) sediment that has accumulated on the Panoche Creek alluvial fan (Figure 8). The last 11,000 years is used for this calculation because the Holocene is the period since the last glaciation; the climate through the Holocene has been reasonably similar to today's climate. Several assumptions are incorporated into this calculation, including: (1) all sediment delivered to the alluvial fan is deposited there (i.e. no sediment is removed from the system by the San Joaquin River or wind); (2) the alluvial fan has a relatively uniform thickness of Holocene sediment, or at least that the average thickness is on the order of 10 to 20 feet; and (3) the average density of sediment on the alluvial fan is 100 pounds per cubic foot. Based on these assumptions, and a simple map of the Panoche Creek alluvial fan (Figure 8), the approximate long-term average annual sediment yield for the PSCW is 800 to 1,600 tons per square mile. These values are within the range of values from earlier studies.

5.2 Study Area

The *study area* investigation involved utilization of observations from previous studies and reports, coupled with field observations noted during the April 1998 reconnaissance and data collection activities. There were two major components of investigation in the *study area*. The first addressed vegetation characteristics and range management, including upland, floodplain, and riparian areas. An evaluation of BLM range allotments and utilization was also conducted, as discussed in Section 5.2.1. The second component of the *study area* investigation involved conducting an inventory of major erosion features, including identification of location, areal coverage, and potential erosion for each feature. Results from this component of the investigation are summarized in Section 5.2.2. Map 1 provides a visual depiction of the results of the *study area* erosion feature inventory, and Figure 9 shows vegetation types along the channel between the confluence and I-5. In the portion of this reach near I-5, there are areas of agricultural disturbance associated with utilization of the adjacent land for irrigated cropland.

5.2.1 Vegetation Characteristics and Range Management

In the approximately 30-square-mile *study area* there are three broad plant community types: (1) upland vegetation located on the watershed *study area* hillslopes; (2) floodplain vegetation, located on terraces adjacent to channels (Panoche Creek, Silver Creek); and (3) riparian vegetation, located immediately adjacent to the channel at channel grade.

<u>Upland Vegetation (annual grassland)</u>

Upland vegetation is dominated by annual grasses with a minor forb and shrub component. Dominant grasses include red brome (*Bromus madritensis* ssp. *rubens*), ripgut (*Bromus diandrus*) and wild oat (*Avena fatua*). Well represented forbs include filaree (*erodium cicutarium*), storksbill (*Erodium botyrys*), lupines (*Lupinus* spp.), and owl's clovers (*Castillja* spp.). The shrub component includes two species of fourwing saltbush (*Atriplex polycarpa*, *Atriplex spinifera*), with scattered populations of Mormon tea (*Ephedra* spp.), rabbitbrush (*Chrysothamnus nauseosus*), and greasewood (*Sarcobatus vermiculatus*). Species composition and forage production (cover) for any given year are influenced by timing and amount of precipitation (McNaughton, 1968; Pitt and Heady, 1978), by mulch residues from the previous year's growth and by fire disturbance (Cotterill, 1998).

Plant community mapping in April 1998 indicated a strong relationship between slope aspect and species composition, and percent cover. North and northeast slopes were dominated by ripgut and wild oat, while more xeric south slopes were dominated by red brome. Average cover on south-facing slopes was lower than on north-facing slopes, with an estimated 70 to 90 percent grass cover on north slopes and 20 to 40 percent, or less, cover on south slopes. Cover of 20 to 40 percent on south slopes is attributed to the above average winter precipitation for 1997-1998. Narrative accounts indicate that the south facing slopes are often barren of cover in dry years (Cotterill, 1998).

<u>Floodplain Vegetation</u>

The floodplain plant community is located on the terraces above the active channel in the *channel incision area*. It is divided into two sub-categories. The first is located on the terrace (T2) adjacent to the active channel, and the second is located on an older, slightly higher terrace (T3).

The T2 plant community is a shrub-dominated plant community, comprised primarily of fourwing saltbush (*Atriplex lentiformis*), and saltcedar (*Tamarix* spp.) An understory of annual grassland is present where openings in the shrub canopy occur. Saltcedar distribution is not continuous along the edge of the channel, but occurs in intermittent, dense stands. Scattered rather than continuous distribution may be attributed to the age of the invasion, to limited water, or to disturbance by fire or grazing. Saltcedar invasion in the T2 community is most dense on the western bank of the confluence area, where it comprises an estimated 50 percent of the plant community. Saltcedar invasion continues at a similar density upstream along the left (west) bank of Silver Creek for approximately one-half to one mile. Saltcedar invasion continues only in small, intermittent stands or single trees past the confluence area upstream along Panoche Creek.

The T3 plant community is an annual grassland with a moderately well-represented forb and a scattered shrub component. Dominant grasses include soft chess (*Bromus hordeacus*), red brome (*Bromus madritensis* ssp. *rubens*), and foxtail barley (*Hordeum* spp.) Common forb species include yellow sweetclover (*Melilotus officinialis*), seepweed (*Sueda* spp.), and filaree (*Erodium* spp.), and fourwing saltbush (*Atriplex lentiformis*) is the most well-represented shrub component.

Cover in both floodplain plant communities was excellent for the 1997-1998 season, averaging by visual estimate between 80 and 100 percent. This cover is thought to be due to the large amount of winter precipitation for this time period, and to the exclosure of livestock.

<u>Riparian Vegetation</u>

Riparian vegetation is represented by historic, isolated stands of cottonwood (*Populus fremontii*) on old floodplain terraces upstream of the *channel incision area*, and by small colonies of cattail (*Typha* spp.) and bulrushes (*Scirpus* spp.) directly adjacent to the active channel. One large population of cattail occurs at the mouth of Silver Creek, indicating the availability of perennial shallow water in this area. There is no riparian forest corridor. In the *channel incision area*, the annual grassland (floodplain plant community) extends to the edge of a vertical cutbank, dropping immediately to the channel grade, with no transition through riparian vegetation. In these locations, the grassland or grass/shrub community vegetative cover was estimated to be 90 to 100 percent; thus it appears there is little correlation between bank stability and type of vegetative cover in the *channel incision area*, although changes in plant communities adjacent to the channel were coincident with areas of massive bank erosion. Shifts from a shrub-dominated community to a grassland or grassland/shrub community commonly occurred where the lower terrace (T2, *Atriplex*/*Tamarix*) had been eroded, leaving the next higher terrace (T3, annual grassland or *Atriplex*/annual grassland) adjacent to the active channel. Changes in plant community at the streambank are therefore caused by physical changes (e.g., bank erosion) in the channel system. Different plant communities do not seem to differ in the level of bank protection they provide.

During vegetation mapping in the spring of 1998, cottonwood regeneration was noted directly adjacent to the active channel in the *channel incision area*, in the form of new shoots on flood-displaced snags. If a perennial water source continues to be available throughout the 1998 growing season, it is likely that some of these shoots will survive. However, many may not have developed sufficient rooting depth to draw upon subterranean water, and will probably die. Regeneration from established young-tree stage cottonwood stands on terraces above the channel is not likely. Although these stands have sufficient rooting depth to utilize the channel water supply (either ephemeral surface water or perennial shallow groundwater), new cottonwood starts will not survive at this distance from the channel water supply.

<u>Range Management</u>

Of the 16 allotments managed by the Bureau of Land Management (BLM) in the PSCW, two are contained within the approximately 30-square-mile *study area* - the Silver Creek allotment (Allotment #4426) on the south end of the *study area*, and the Panoche Hills allotment (Allotment #4386) on the north.

Management of the allotments is focused on three primary objectives: (1) production of forage; (2) maintenance of soil cover through the dry season; and (3) protection of native saltbush (*Atriplex* spp.) for preservation of game bird habitat. Management actions designed to meet these objectives include: (1) a required residual dry matter (RDM); (2) season of use; and (3) stocking rate. Management practices that are recommended but not required for permitees include livestock class and distribution.

Only one allotment within the watershed is currently run by an owner-operator. The remaining 15 allotments are leased to commercial stocker operators. Implementation of management improvements requires a high level of cooperation with these operators.

Permitees are required to leave a minimum RDM of 700 pounds per acre on upland sites, and 1,000 to 1,200 pounds per acre on bottomland (Cotterill, 1998). RDM is defined as the non-utilized portion of a season's forage production that will provide soil cover until the first fall rains initiate growth of new annual grasses. RDM levels are based on a study that found mulch levels were correlated to forage production in the following season (Bartolome, et al., 1980). However, for range sites receiving less than 25 cm (10 inches) of mean annual precipitation (as is the case in the lower watershed and *study area*), this same study found no significant influence of mulch to standing crop. Therefore, setting utilization levels based on Bartolome, et al. (1980) cannot be viewed as reliable for the range sites in the lower watershed.

Season of use begins after winter annual grasses have "greened-up", as early as December, when available water, green feed and cool temperatures provide ideal weight-gain conditions. In an average year, livestock are removed from all BLM allotments by no later than April 30 the following spring. The management objective is to limit impacts to the cooler, more moist riparian areas by removing livestock before they come down from the uplands to gather in these areas. The April 30 date is sometimes extended if temperatures are cool and forage production is abundant.

<u>Silver Creek Allotment</u>

The Silver Creek Allotment is stocked with commercial steers from December 1 through April 15, with a minimum RDM of 700 pounds per acre. In the 1997-1998 season, the operator had stocked "light-weights", which are steers weighing between 300 to 400 pounds. Many of these steers also have some Brahma parentage, a breed of cattle known for its tolerance of hot, dry conditions, for its ability to travel long distances to water, and for its agility on steep, difficult terrain. These "light-weights" are therefore an excellent class of livestock for this allotment, and may limit adverse impacts associated with trailing and gathering through their superior distribution patterns. Livestock distribution is also maintained by extensive water developments throughout the allotment.

The average RDM level for the years 1983-1997 was 1,694 dry pounds per acre and for the 1993-1994 season of use, stocking rates dropped by 700 animal units (AUMs) (BLM, 1997). Based on these numbers, the Silver Creek allotment may be described as having excellent average cover and, between the years of 1983-1994, increasingly light utilization levels. Reductions in stocking rates for this period may reflect seasonal fluctuations in forage production or drought-caused termination of the grazing season.

In 1997, two new pastures were fenced on the Silver Creek Allotment. The new pastures are part of a management objective to improve distribution, season of use, and protect riparian revegetation efforts. The first pasture, an 80-acre riparian pasture adjacent to shipping pens, includes approximately one mile of Silver Creek. This pasture may be used by the permitee to hold steers for several days after unloading and before turning out to the upper creek pasture. Utilization of this pasture occurs at the earliest time during the grazing season, before woody riparian vegetation has begun to green up (typically in March or April). However, because stocking of this pasture is compressed into a short, intense utilization period, impacts from trampling may harm plants and cause soil erosion, particularly at sensitive bank areas.

The 3,000-acre upper creek pasture includes both upland and riparian vegetation. Steers utilize this pasture, or the 15,000-acre upland pasture from a few days after unloading until the pull-off date in April.

Panoche Hills Allotment

The Panoche Hills allotment has historically been stocked with sheep (BLM, 1981). Sheep are the preferred class of livestock for several reasons. First, although sheep will browse the saltbush shrubs (*Atriplex* spp.), they generally do not damage the plant structure by trampling. Second, distribution of sheep is achieved by herding and, therefore, utilization is managed on a daily basis by the herder. This type of intense management has the potential to significantly limit adverse impacts to the range resource.

Management requirements for the Panoche Hills Allotment include a minimum RDM of 700 pounds per acre in the upland and 1,000 to 1,200 pounds per acre in the bottomland, and also include a maximum bedding time of three days. At the time of field work in the spring of 1998, no livestock were noted in the *study area* part of this allotment. Adverse impacts from historic use were minimal in the riparian area of Panoche Creek above the confluence, and in the upland *study area* 1998 conditions (percent cover and forage production) appeared excellent.

Summary of Study Area Livestock Impacts

Adverse impacts associated with livestock utilization in the PSCW assessment *study area* (which includes the Silver Creek Allotment) were noted for the 1997-1998 grazing season. These impacts were concentrated around drainages in the majority of both upland and riparian areas of Silver Creek. Bank erosion and incised channels appeared to be correlated to trampling and heavy browsing concentrated around these numerous small drainages. Herbaceous plant cover was low to absent in some of the drainage bottoms, and adverse impacts to shrub populations (*Atriplex* spp.) were also noted. Damage to native shrubs from hedging and trampling is believed to negatively impact native game bird habitat (Cotterill, 1998; Moore, 1998). Upland slopes outside the heavily impacted areas were characterized by excellent cover, with a limited amount of erosion. In selected drainages, percent cover appeared to be excellent, allowing the drainages to function as buffers for potential sediment contribution to the nearest downstream channel.

Low vegetative cover and trampling also were noted in the riparian area of Silver Creek, and appeared more severe than the same categories of impacts occurring in upland drainages. Bank failure appeared to be related to trailing along stream banks in some areas, although in other areas bank failure appeared to be related more to soil texture. Salting locations were noted on the first terrace immediately adjacent to the stream channel, a location that may encourage trampling of erodible banks. In summary, much of the riparian vegetation along Silver Creek appears to be heavily impacted by livestock congregation, thus contributing to bank erosion and disturbance of the native plant community.

Adverse impacts of soil erosion and bank instability associated with grazing historically have stemmed from either beginning the grazing season too early, or extending it too late (BLM, 1981). Soil erosion may be accelerated from grazing by allowing access by cattle too early in the season (Vallentine, 1990). If livestock are allowed onto soils that are wet or that have not had sufficient time to become stabilized by vegetative cover, hoof action may cause compaction, slippage, or erosion. Utilization of range resources too early in the season also may force utilization of saltbush, which is detrimental to wildlife cover, and is believed to decrease plant vigor and production (Cotterill, 1998). Utilization too late in the season may also force cattle to forage under these shrubs for remaining green fodder, and shrubs are often damaged by aggressive grazing behavior (Cotterill, 1998). Furthermore, utilization of annual grasses in a late stage of their growth cycle is thought to reduce total RDM cover by eliminating the potential for plant growth after grazing.

The relationship of livestock impacts to plant community composition changes is the subject of a large body of research. In annual grassland systems, temperature, rainfall, soil type and exposure have been associated with species composition (Pitt and Heady, 1978; McNaughton, 1968), while the effects of grazing intensity on species composition and productivity are frequently confounded by responses of annual species to these same variables (Rosiere, 1987). In riparian systems, improper management of livestock may result in adverse impacts to the plant community (Clary, 1995; Bryant, et al., 1972), and to the stability of the channel system, and may provide conditions favorable to the introduction of exotic species (Kattleman and Embury, 1966).

5.2.2 Erosion Features

Erosion features were inventoried and mapped within the *study area* during April 1998 field activities. The following major categories or types of features were identified and are shown on Map 1: cattle hoof disturbance, gullying, landslide mass wasting, general mass wasting, overland/rill, bedrock mass wasting, road cut bank, and Tumey Tunnels (piping). Each feature was also categorized for erosion potential based on visual observation (see Map 1). A "high" erosion potential applies to features which would actively erode in the next rainstorm, and a "low" erosion potential applies to features which may have eroded in the past, but now are stable and vegetated. "Moderate" erosion potential applies to those features which may have eroded in the past, are somewhat stable, and still appear to have potential to erode, but not as actively as the "high" erosion potential features. General observations for these features are summarized in the following discussion. Table 6 provides a summary of total area, number of observed locations, land use in surrounding areas, and range of erosion potential for each type of feature.

As shown in Table 6 and on Map 1, the cattle hoof disturbance erosion feature covers the largest total area (only 2 percent of the *study area* and 0.2 percent of the total watershed area), with overland (interrill)/rill erosion also covering a large area. In some portions of the *study area*, such as in Panoche Hills, ungrazed barren slopes were observed indicating that geology and soils, and not an effect of grazing intensity or pressure, are the controlling factors that lead to development of these barren slopes. Also, annual precipitation is generally held to be a critical influence on percent plant cover in annual grasslands, and may cause as much variation as soils, aspect, or grazing pressure (McNaughton, 1968). Aspect and vegetative cover (from field observations), along with geology (from Bartow, 1996), also appear to be factors influencing erosion potential in the lower watershed. Land use (grazing) exacerbates the erosion potential in the lower watershed areas already vulnerable to natural erosion processes, although limited cattle hoof disturbance could provide benefit to slope stability and erosion reduction, in some cases, by possibly creating a less adverse environment for slope stability. However, the erosion potential could be worsened by overuse; an excessive amount of soil imprinting; and imprinting, compaction, and slippage by cattle during wet conditions.

In most areas, a pathway (i.e., stream or gully) for transport of sediment from overland sources was observed. One notable exception to this was a 3-mile reach of Silver/Panoche Creek near the confluence where an ungrazed, fenced area with continuous, dense grass cover was observed between the highly erodible hillslopes and the Silver/Panoche Creek channel. This high terrace extended approximately 1.5 miles downstream from the confluence, along the southeast side of Panoche Creek, and approximately 1.5 miles upstream from the confluence, along the east side of Silver Creek. Along Silver Creek upstream from this reach, grazing of this riparian/upland zone was observed and appeared to coincide with gullied, deeply incised stream channels. Although gully erosion does not cover a large area, these gullies are located where flow is concentrated. For example, surface water draining from the southeast part of the *study area* is conveyed through gullies to Silver Creek. The gullies appear to be actively forming and headcutting, thus delivering sediment to the Panoche Creek system. Mass wasting in streambank areas also appears to be contributing to the sediment load throughout the *study area*.

Bedrock mass wasting, landslide mass wasting, road cut bank, and Tumey Tunnel (i.e., soil piping) erosion features were not large contributors to sediment loading in Panoche Creek, relative to contributions from cattle hoof disturbance, gullying, general mass wasting, and overland/rill erosion features. Where observed, these features did not appear to be providing large volumes of material directly to downstream areas.

Comparison of *study area* geology (from Bartow, 1996) with the erosion feature inventory, provides some explanation for trends observed between sub-drainages (Map 1). Soils in the northeastern portion of the *study area*, southeast of Panoche Creek, are derived from the

Kreyenhagen Shale, which contains brown shale with diatomite and gypsum. This area was observed to have some landslides and barren eroding slopes where grazing was heavy. Directly south of this area, on hillsides east of Silver Creek, soils are derived from the Lodo Formation which contains claystone and siltstone with sandstone. All south-facing slopes in this area were barren, and cattle grazing was also observed, resulting in cattle hoof disturbance. Similar observations of barren slopes in the Lodo Formation were made for Panoche Hills north-northeast of the confluence of Panoche/ Silver Creeks, except effects from cattle grazing were not evident. Thus, it appears that the Lodo Formation results in naturally unvegetated and, therefore, highly erodible soils, particularly on south-facing slopes, which are drier than north-facing slopes. This geologic information provides some explanation for differences in erosion feature occurrence between sub-drainages.

5.3 Channel Incision Area

The *channel incision area* investigation was conducted to evaluate the factors and processes that most strongly influence the sediment budget of the *channel incision area* and, if possible, to estimate amounts and rates of sediment erosion, deposition, and transport. To evaluate channel stability and long-term geomorphic trends, analyses were conducted to identify historical changes in longitudinal profiles, channel cross sections, and channel plan form by evaluating a variety of archival information. Field reconnaissance was conducted in the Spring of 1998 to identify and characterize areas of active geomorphic change. Transport of suspended sediment, based on preliminary data collected by the USGS at the Panoche Creek at I-5 gaging station, was also modeled.

Based on distinct geomorphic characteristics of creek reaches, and to simplify discussion, the *channel incision area* is subdivided into several segments. The “confluence area” has the Panoche Creek/Silver Creek confluence at its center; it extends about 4,000 feet upstream and downstream of the confluence. Downstream of the confluence area, is a reach designated as the “fan apex reach”; it extends to about 2,000 feet downstream of I-5. The lowest reach, which is designated the “alluvial fan reach”, extends downstream to at least the California Aqueduct.

This section is organized by the type of data and analyses performed. First, Section 5.3.1 presents an analysis of how the Panoche Creek streambed elevation has changed through time by comparing longitudinal profiles from four different map vintages. In Section 5.3.2, comparisons of cross section measured in 1990 and 1998 are made to characterize amounts and rates of bed and bank erosion. Next, historical maps and aerial photographs are used to evaluate changes to the Panoche Creek plan form (Section 5.3.3). Section 5.3.4 provides a presentation and interpretation of field evidence for geomorphic changes that occurred as a result of the large flows of February 1998. Sediment transport sampling data, collected by the USGS, are also used to estimate the total sediment load moved during the large flows of 1998. A summary of these analyses is provided in Section 5.3.5.

5.3.1 Longitudinal Profiles

The four longitudinal profiles presented in Plate 1a show substantial historical changes in channel bed elevation between 1924 and 1990. The profiles extend from upstream of the Fresno/San Benito County line to downstream of the California Aqueduct. Based on the profiles, incision has been greatest from the confluence of Silver Creek and Panoche Creek to I-5. The reaches upstream of the confluence also have experienced considerable but lesser amounts of incision. In the reach downstream of the confluence, the channel thalweg appears to have incised from 25 to as much as 40 feet between 1924 and 1990 (Plate 1a). These incised amounts, although greater than what were estimated based on field observations, show that significant change to the fluvial system has occurred over a relatively short time.

At the downstream end of the profile, the 1920s and 1950s profile lines converge, showing that this reach of the stream was relatively stable over the 30-year interval. In fact, over part of this reach, the 1950s line is higher than the 1920s line, suggesting that aggradation occurred between the 1920s and 1950s. The sediment deposited downstream of the California Aqueduct likely originated upstream in the areas of significant incision between the 1920s and 1950s. Based on the profiles, the reach of stream along which there has been the greatest degree of incision correlates spatially with the location of cultural alteration (cultivation, diversion works, gravel mining, etc.). Cultural activities likely to have impacted channel bed elevation include: construction of a concrete diversion dam about one mile downstream from the Panoche/Silver Creek confluence in the late 1880s, straightening and shortening of the stream locally across the I-5 corridor, aggregate mining, construction of earthen berms across the channel in several places, grading and regrading of roads at channel crossings, and straightening and shortening of the stream downstream of I-5 (Plate 1d). Two nearly horizontal reaches of the 1920s era profile are present (Plate 1a): (1) at the diversion dam where the 1960s era USGS gaging station was operated; and (2) downstream of I-5. These reaches reflect sediment deposition behind irrigation diversion structures. The upstream diversion dam, which likely ponded sediment between 1887 and about the early 1920s resulted in deposition of a fill terrace and historical sediment that extends as far as 3,000 feet upstream of the diversion dam. The downstream earthen diversion dam is not as obvious on today's landscape, probably because channel banks and terraces along that reach of the stream have experienced significant modification for agricultural purposes.

Comparison of the 1990 profile with earlier profiles shows two areas of significant channel lowering, both related to channel modification. At the location of the aggregate mining operation upstream of I-5 (Plate 1d), the channel is much lower relative to the earlier profiles than elsewhere along the stream. This is likely a result of aggregate extraction within and adjacent to the channel. Directly downstream of I-5, the 1990 profile is also significantly lower than earlier profiles. This likely is a result of the changes imposed on the channel when I-5 was constructed. Included in these changes are: (1) shortening and straightening of the stream through this reach by approximately 67 percent, and (2) armoring of the channel directly below the I-5 bridge. These changes, together with abandonment of the early earthen diversion structure, may be responsible for the incision downstream of this reach.

5.3.2 Channel Cross Sections

Channel cross sections were surveyed at 15 locations along Panoche Creek (Plate 1c and Appendix D). Comparison of these 1998 surveys with cross sections measured in 1990 shows differences in channel geometry and flood capacity between upstream and downstream reaches, and changes in channel geometry between 1990 and 1998. This 8-year interval included two very wet winters (1995 and 1998). Unfortunately, because of a lack of information describing the precise locations of the 1990 measurements, several of the 1998 surveyed cross sections may have been surveyed in slightly different locations than the 1990 measurements.

In the confluence area, the creek is deeply incised, and there is abundant evidence for recent erosion of the channel banks and bed. The confluence area (see cross sections 55, 56, 57, and 58 on Plate 1c and Appendix D) has few meanders, and a slightly steeper slope (0.006 to 0.007 ft/ft) than farther down the creek. Cross sections measured in the confluence reach show that the creek is incised as much as 45 feet below the adjacent stream terraces or alluvial fans. Banks bounding the flat-bottomed channel are typically near vertical, absent of vegetation, and very susceptible to sloughing and failure. Along much of this reach of the stream, banks on both sides of the channel appear to have experienced erosion during the 1998 winter (see photos on Plate 1). There is little evidence that 1998 flood flows reached the top of the banks; the lowest, historical terraces that are 6 to 8 feet above the channel bottom did not appear to have been inundated, perhaps because the channel through this reach is relatively wide. The channel bed in the confluence reach is typically sandy, has low relief, and is absent of vegetation. In at least two places (near cross sections 56 and 58), pre-Quaternary bedrock was exposed in the channel bottom. Thus, the channel has incised through the thick package of Holocene (?) valley fill to the bottom of the fill.

Comparison of 1990 and 1998 cross sections from locations 57 and 58 shows that approximately 1,900 and 1,500 square feet of material was removed from locations 57 and 58, respectively, between 1990 and 1998. The distance between the two cross sections is approximately 2,800 feet (0.5 mile). Multiplying this distance by the smaller cross-sectional area removed (1,500 square feet) yields a volume estimate of approximately 4 million cubic feet (92 acre-feet, or, assuming a density of 100 pounds per cubic foot, about 200,000 tons). This analysis provides an average rate of erosion of 40,000 to 50,000 tons of sediment per mile of stream per year from the channel banks in this reach. This reach of Panoche Creek experienced perhaps the greatest bank erosion of all areas within the *channel incision area* over recent years. Thus, this estimate of 40,000 to 50,000 tons/mile per year should be used only for the confluence reach.

Downstream of cross section 55, in the fan apex reach, the valley begins to widen and Panoche Creek leaves the foothills and spills onto its alluvial fan. Here the channel adopts a more sinuous form. The stream also is not as deeply incised; recent bank erosion is discontinuous and found primarily on the outside of bends (Plate 1d) and channel cross sections are generally wider and shallower than upstream (Plate 1c). Terraces adjacent to the channel are continuous, broad, flat surfaces that are extensively utilized for agriculture and are typically not more than 10 to 25 feet above the thalweg. Channel banks are vegetated except on the outside of some bends where bank erosion recently occurred. At the locations of active bank erosion, the banks are unvegetated and near vertical. Where significant time has elapsed since the most recent episode of bank erosion, banks typically have a colluvial deposit at their base, and the once near-vertical cut has evolved into a more subdued, gentler slope through erosion of the top of the bank and accumulation at the base of the bank. In a few places, these “stable” banks are sites of willow and cottonwood stands. Such vegetation will serve to protect the bank during future moderate-scale floods. The presence of this vegetation suggests that the recent large floods (1995, 1998) did not erode as pervasively in this reach as they did upstream, in the confluence area. Many old meander scars, with terraces 5 to 15 feet above the present channel, are now being used by farmers or serve as a buffer between farms and the active stream. Many of the lower terraces were inundated during the high flows of the 1998 wet season. The relations and observations described above suggest that the fan apex reach is not incising or rapidly eroding its banks like the confluence area reach; rather, this reach shows some of the processes common to alluvial fans (e.g., aggradation and episodic bank erosion).

Downstream of I-5, on the alluvial fan reach, the channel gradient gradually decreases from approximately 0.004 to 0.003 ft/ft (Plate 1a). The channel typically is confined to widths less than about 600 feet and the thalweg is generally less than 20 feet below the adjacent terraces. Along most of this reach, agricultural use extends to the channel banks, and in some cases orchards or vineyards were inundated by floods and sediment of the 1998 wet season (see photograph 9 on Plate 1b). Comparison of 1990 and 1998 cross sections (cross sections 41, 40, 36, 34, and 33 on Plate 1c) shows that this reach is characterized by deposition. The 1998 field reconnaissance data support this interpretation. Many of the lower terraces were observed to have sand deposits up to several feet thick blanketing the soils and vegetation. There were some sites of bank erosion, and a few places for which thalweg erosion (incision) was observed; however, in general, the reach of channel downstream of I-5 experienced deposition during the winter of 1998 (Plate 1d).

During the spring of 1998 (as part of the current study), Bull's (1960) channel width measurement sites (Plate 1c) were reoccupied. Bull (1960) measured channel widths in 1959 and compared these field measurements with estimated channel widths from 1854 topographic maps at multiple points between the gravel operation and the California Aqueduct. The locations of these measurement sites and the 1854, 1959, and 1998 measured channel widths are shown on Plate 1c. Figure 10 provides a plot of channel widths through time at six of Bull's (1960) measurement sites. Because Bull's (1960) original measurements were not orthogonal to the channel, the calculated widening rates should be thought of as "apparent" widening rates. The conclusion to be drawn from Figure 10 is that most of the lower channel (from the old aggregate operation upstream of I-5 to the California Aqueduct) is widening at rates less than about 3.0 ft/yr. Discrete episodes of bank erosion and channel migration likely are responsible for most of the channel widening. The widening likely is not occurring at a constant rate; thus, connecting the data points from different years with a straight line as shown on Figure 10 probably is not representative of the processes. The site between sections 30 and 31, with an apparent widening rate of about 10 ft/yr, likely experienced a single episode of channel migration in the 1854 to 1959 interval. On a year-to-year basis, most reaches of the channel will maintain a stable channel configuration and width; however, infrequent episodes of rapid, possibly catastrophic bank erosion occur. An example of rapid bank erosion occurred during the winter of 1998 approximately 500 feet upstream of Brannon Road (Plate 1d). Here, the terrace adjacent to the left bank is approximately 21 feet higher than the thalweg, and is separated from the thalweg by a freshly eroded vertical scarp that is concave toward the channel, and as much as 75 feet from the former channel margin. During the winter of 1998, approximately 7,000 cubic yards (9,500 tons, assuming a sediment density of 100 pounds per cubic foot) of terrace material was eroded from the left bank leaving a concave “scallop” in the channel plan form. Delivery of this large volume of sediment into the stream is apparent downstream, where sand blankets the banks and low terraces of the creek for hundreds of feet.

Bull (1960) also measured the depth of the channel near North Avenue in 1955 (Plate 1c). In 1955 the channel bed was approximately 25 feet below its banks; in 1998 the channel bed was approximately 12 feet below its banks. Thus, at least at this point along the creek, the channel has aggraded since 1955, an observation consistent with findings based on longitudinal profiles, cross sections, width measurements, and the current study’s 1998 field reconnaissance.

The volume of sediment produced by channel bed erosion in the confluence area was predicted, as part of the current assessment work, by estimating a long-term average rate of bed lowering and multiplying this rate by the length and average width of the channel. Based on comparison of the 1924 and 1990 longitudinal profiles, it was estimated that the channel bed was lowered by an average of about 20 to 25 feet over the *channel incision area* reach. However, based on the 1998 field reconnaissance and measurement of channel cross sections, the recent aggradation in the alluvial fan reach and possibly in the fan apex reach has reversed the incision shown by Plate 1a in the downstream reaches of the *channel incision area*. Thus, an estimate of a long-term volume of eroded bed material was developed only for the confluence area. As a conservative estimate, an average incision of 15 feet over the approximately one-mile-long reach downstream of the confluence is assumed for the 1924 to 1998 period. If an average active channel width of 300 feet is also assumed, a total volume of about 24 million cubic feet (1.2 million tons, or 550 acre-feet) of material was eroded from the channel bed over the 66-year period. This translates to approximately 15,000 to 20,000 tons/yr/mile of channel over the one-mile-long reach of channel downstream from the confluence. This number should be used only for the confluence area, because other reaches are not experiencing similar rates of incision.

Another estimate of watershed sediment yield can be derived by estimating the volume of sediment that was trapped upstream of a diversion dam about one mile downstream of the confluence of Panoche Creek and Silver Creek. At least 3 to 5 feet of sediment is ponded behind the dam over an area of approximately 50 acres (photograph 3, Plate 1b). Based on aerial photograph and topographic map interpretation, a minimum estimate for the volume of sediment is 8 million cubic feet (190 acre-feet), and a maximum is about 16 to 20 million cubic feet (380 to 470 acre-feet). To calculate the average annual volume of sediment trapped behind the dam, the period during which the dam was in operation and ponding sediment must be known. Bull (1960) states that the ditch fed by the small concrete dam and outlet works was constructed in 1887. Therefore, the dam was probably also constructed in 1887. The date when the dam ceased ponding sediment is not as well constrained. The dam is not shown on the Tumey Hills 1924 USGS 7.5-minute topographic quadrangle, although the related ditch is shown. In a consulting engineer's report, Harding (1922) describes the method of irrigation - flooding the agricultural lands near Panoche Creek in winter using the concrete diversion dam as well as a downstream earthen dam to divert runoff from the creek (Plate 1d). He evaluates the value of the land, based on the extent and availability of water for irrigation. Harding (1922) describes the concrete diversion works as well as a "partly built multiple arch dam", of which little evidence was found in the current study. The diversion works and ditches were working at the time of Harding's visit, but were in need of repair. The conclusion of Harding's report was that, given the unreliability of water supply and the cost of needed repairs to the system, financing repairs and the additional needed improvements would be unwise. Thus, use of the diversion dam probably ceased in about 1922, and the dam probably had a lifespan of about 35 years. Using the sediment volumes calculated above and the 35 year period, the approximate average annual volume of material trapped behind the dam was between 200,000 and 600,000 cubic feet (5 to 13 acre-feet per year, or 11,000 to 29,000 tons per year, assuming a sediment density of 100 pounds per cubic foot). Using the watershed area upstream of the diversion dam (293 square miles), an average annual sediment yield of 0.02 to 0.04 acre-feet per mile (37 to 100 tons per square mile) can be calculated. These values are considerably lower than other estimates of sediment yield, probably because the diversion dam had a low trap efficiency and/or because the diversion dam did not continuously operate over the full 35 years. Harding (1922) describes abundant sediment deposition on the agricultural fields as a result of this method of irrigation. If only bedload was trapped behind the dam, then the 1998 estimates, which are slightly less than 10 percent of other yield estimates (Table 3), suggest that bedload for this system may account for on the order of 10 percent of the total sediment load.

5.3.3 Channel Plan Form

Historical maps and aerial photographs were used to evaluate changes in channel plan form through time (Plate 2). Based on the stream's plan form and its behavior over the last 60 years, the stream was subdivided into several reaches, each having distinct behavioral patterns: (1) the confluence area; (2) an approximately one-mile-long reach below the confluence area with the old earthen diversion berm at the downstream end of the reach (Figure 11); (3) the reach between the diversion dam and approximately 2,000 feet downstream of I-5; and (4) from approximately 2,000 feet downstream of I-5 to the California Aqueduct. Reaches 2 and 3 for this analysis fall into the reach previously designated as the fan apex reach.

In the confluence area, aerial photographs and archival maps (Plate 2) show that the stream has progressively eroded laterally into the wide Holocene and Pleistocene (?) valley fill sediment. Figure 11 (comparison of 1990 and 1998 air photos) and cross sections 57 and 58 (Plate 1c) show that, over the last eight years, bank erosion has been severe in the confluence area. The cross sections illustrate that most of the geomorphic change has been caused by bank erosion and that there has been relatively little change in thalweg elevation. Relatively competent pre- Quaternary bedrock is exposed in the channel bed in several places, slowing the rate of additional incision. Perhaps because the stream has reached a more stable, less easily eroded base level, bank erosion has become the dominant process by which the stream expends energy.

Also apparent from evaluation of archival maps and aerial photographs (Plate 2) is the downstream migration of the confluence of Panoche Creek and Silver Creek. Between 1924 and 1990 the confluence migrated approximately 1,800 feet downstream. Most of this migration appears to have occurred between the 1920s and 1950s. Because of the coincidence in timing, the migration of the confluence and much of the early incision in this reach is postulated to be a response to: (1) termination of use of the concrete diversion dam; and (2) the 1935 to 1945 period of above average daily and annual rainfall (Bull, 1960). Once flashboards were no longer installed in the dam each winter, the stream likely began to incise through the ponded sediment behind the dam. This incision likely migrated upstream in the form of a knickpoint (or knickpoints), and as the channel bed lowered, the confluence migrated downstream. By the 1950s, the stream may have finished responding to opening of the dam and migration of the confluence ceased or slowed. Between 1990 and 1998 (Figure 11 and Plate 2), the confluence does not appear to have migrated at the same rate as it did between the 1920s and 1950s, if it migrated at all. This change may be because the rate of incision has decreased as a result of the bedrock encountered in the stream bed.

The reach of stream that includes the concrete diversion dam, the USGS 1960s era gaging station, and an earthen berm (Figure 11 and Plate 2) is defined by its lack of meanders and narrow, confined channel. This reach has undergone little lateral migration over the period recorded by archival maps and aerial photographs presented in Plate 2. Based on field reconnaissance and the longitudinal profile presented on Plate 1, this reach of the stream has incised through time.

From the earthen dam downstream past I-5, the channel has a meandering pattern, and the meanders have migrated through time. Based on the 1998 channel plan form, the meander amplitude is generally 0.2 to 0.4 times the meander wavelength. As the meanders migrate, they erode material from the outside of bends and deposit material on the insides of bends (Plate 1d). Because the banks are relatively low, and bank erosion only occurs over short distances along the outsides of some bends, this reach of the stream contributes a much smaller amount of sediment per mile of stream to the watershed yield than the confluence reach.

Between I-5 and the California Aqueduct, in the alluvial fan reach, the channel meanders with shorter wavelengths than upstream. Generally the meanders are confined within the late Holocene to historical “floodplain”. Rarely do the episodes of bank erosion erode material that is outside of the young floodplain. Aerial photographs from 1937 (Plate 2b) show that the stream occupied some of the low terraces and meanders that now are inundated only in the largest observed flows (e.g., 1998), suggesting that there has been some post-1937 incision. The 1937 aerial photographs also show significantly more vegetation growing within the active channel than is observed on later photographs, perhaps because of the lack of large floods in the few years prior to 1937.

5.3.4 1998 Wet Season

In the Spring of 1998, field reconnaissance was performed to identify areas of deposition and erosion and to inspect the effects of the February and March floods. Preliminary streamflow gaging and suspended sediment sampling data from the USGS gage at I-5 were used to estimate the amount of sediment transported past I-5 during the high flows of February and March.

Field mapping

In the 1998 field reconnaissance of May and June 1998, the focus was on identifying areas of active erosion and/or deposition. Field observations are recorded on Plate 1d, and selected photographs taken during the field reconnaissance are shown on Plate 1c. Inspection of Plate 1d reveals several trends from the 1998 flooding:

- Bank erosion is prevalent in upstream reaches of the *channel incision area*;
- Deposition is prevalent in downstream reaches of the *channel incision area*;
- Bank erosion in downstream reaches of the *channel incision area* occurred mainly on the outside of bends;
- There are short reaches of the channel (several hundred feet long) where the channel migrated tens of feet into the adjacent terrace or alluvial fan deposits (Plate 1d);
- Abundant sediment was deposited upstream of two flow constrictions: the bridge crossing lower Silver Creek, and the Fairfax Road bridge; and
- Little hillslope-derived sediment from slopes downstream of the confluence enters the channel in the *channel incision area*.

Bank erosion is most severe in the confluence area and for about 5,000 feet downstream of the confluence. Because the stream is also highly incised through this reach (banks can be greater than 40 feet high), when bank erosion does occur significant quantities of sediment are delivered to the channel. Although areas upstream of the confluence were not mapped in detail, bank erosion and bed incision were observed to persist for at least 2,000 to 3,000 feet upstream of the confluence. Panoche Creek upstream of the confluence is deeply incised and has experienced extensive bank erosion (see cross section 58 on Plate 1c). In the vicinity of cross-section 58, approximately 2.7 million cubic feet (62 acre-feet or 135,000 tons, assuming a density of 100 pounds per cubic foot) of terrace sediment has been eroded from the right bank since 1990; it is possible that all of this bank erosion occurred in 1998 (Plate 1d). Silver Creek also appears to have experienced considerable recent bank and bed erosion from the confluence upstream to the bridge crossing the creek.

Bank erosion between the 1960s USGS gaging station and the California Aqueduct (the fan apex and alluvial fan reaches defined earlier) generally occurs only in areas where flow energy is directed at outside bends of the channel. Because bank heights typically are lower than near the confluence, individual sites of bank erosion deliver less sediment to the creek than similar sites in upstream reaches. However, there are downstream sites that deliver considerable sediment volumes to the stream. For example, the left bank near Brannon Road in 1998 produced approximately 190,000 cubic feet (9,500 tons, assuming a sediment density of 100 pounds per cubic foot).

From field mapping of bank erosion and bank vegetation, changes in plant communities adjacent to the channel were observed to occur coincident with areas of massive bank erosion. Shifts from a shrub-dominated community to a grassland or grassland/shrub community commonly occurred where the lower terrace had been eroded, leaving the next higher terrace (with a greater percentage of grassland species) adjacent to the active channel. Changes in plant community at the streambank are therefore caused by physical changes (e.g., bank erosion) in the channel system. Different plant communities do not seem to differ in the level of bank protection they provide.

In general, sediment deposition in 1998 occurred in several settings: at areas of channel divergence or widening, on the inside of bends, and upstream of the Silver Creek and Fairfax Road bridges. Plate 1d shows that in 1998, downstream of the 1960s era USGS gage, deposition occurred at nearly every site of channel expansion. At these sites, the channel widens, velocities decrease, and the capacity of the stream to transport sediment diminishes. The prevalent deposition on the insides of channel bends also is caused by a decrease in water velocities - the insides of channel bends are often the sites of eddies and slackwater. In some reaches, bank erosion occurred on the outside of bends and deposition occurred on the inside of the same bend (Plate 1d). The Silver Creek and Fairfax Road bridges acted as flow constrictions during the high flows of February 1998 causing deposition upstream of the bridges. The bridge and box culvert at the Silver Creek crossing also appear to be functioning as grade control, preventing the significant incision downstream of the bridge from migrating upstream. Upstream of the Fairfax Road bridge, a blanket of sediment covered nearly all of the low terraces (photographs 13 and 14,

Plate 1c). The large root ball pushed against the bridge piers (photograph 13, Plate 1c) may be the main cause of flow restriction through this reach in 1998.

1998 Sediment Transport Based on USGS Gaging and Suspended Sediment Sampling

Preliminary streamflow gaging and suspended sediment data for the 1998 water year were used to estimate the total suspended sediment load that moved past the Panoche Creek at I-5 USGS gage (#11255575) between January and April 1998. Figure 12 shows a stage/discharge rating curve based on preliminary USGS data. The equation shown in Figure 12 was used to estimate hourly discharge values for USGS preliminary January to June hourly stage values. Hourly discharge values were compared with the suspended sediment concentrations measured by the USGS and a rating curve was developed for this relationship (Figure 13). As is typical, the relationship between discharge and suspended sediment concentration has a great deal of scatter, and the best regression equation does not fit the data very well. However, despite the relatively poor fit, the equation shown in Figure 13 was used to model hourly suspended sediment discharge. Because of: (1) the scatter at the high end of the discharge/suspended sediment concentration data; and (2) the relatively poor statistical relationship between sediment concentration and discharge, the maximum concentration was constrained to 250,000 mg/l. Based on the regression relationships shown in Figures 12 and 13, and the maximum constraint imposed on suspended sediment concentration, an hourly time-step model was developed to estimate the amount of sediment that passed the USGS gage at I-5. A summary of this hourly time step model, showing the total sediment transported for each day, is provided in Table 7. According to the model, between 4 and 5 million tons of suspended sediment moved past the I-5 gage during the winter of 1998. Most of this sediment was transported during two storms in early February.

The 4 to 5 million tons of suspended sediment translates to a watershed yield for the 1998 wet season of approximately 15,000 tons per square mile. This value is on the order of 15 times the average annual amount predicted in earlier studies (SCS, 1976; USBR, 1981). However, streamflows during 1998 were very large, with recurrences on the order of 50 years. Given the poor statistical relationship between suspended sediment concentration and discharge, this estimate must be qualified as probably no more accurate than an order of magnitude. Also, the estimate is for suspended sediment only; bedload, which can be a significant fraction of the total load in sand-bedded channels, is not accounted for in these estimates.

The highest suspended sediment concentrations measured by the USGS occurred on the falling limb of flood hydrographs (personal communication, C. Kratzer, USGS). Possible interpretations of this phenomenon are probably two-fold, either: (1) large volumes of sediment are coming from distant parts of the watershed, and the sediment does not travel to the I-5 gage until the flood peak has passed; or (2) the high stages themselves are responsible for initiating a process that delivers large volumes of sediment to the system. The latter possibility may be related to the pervasive bank erosion near the confluence. Sloughing and caving of the near-vertical, sometimes higher than 40-foot-tall banks, may happen after the stage has reached its peak and begins to decline. Then, the saturated banks are more likely to fail than earlier in the flood event.

5.3.5 Summary of Channel Incision Area Interpretations and Conclusions

The Panoche Creek *channel incision area* has experienced dynamic geomorphic change over the past 60 years. For this project, historical changes since 1924 were characterized, and geomorphic effects of 1998 floods were described. Upstream reaches, near the Panoche Creek - Silver Creek confluence, have been the site of tens of feet of incision, and more recently, severe bank erosion. Between the confluence area and I-5, the creek has experienced incision and bank erosion, primarily on the outside of bends. Erosion along this reach is relatively minor compared with the historical erosion in the confluence area. Panoche Creek between I-5 and the California Aqueduct generally has been a reach of sediment deposition with only localized bank erosion.

Long-term estimates of average annual sediment yield for the PSCW include: (1) estimates from previous studies of 500 to 1,100 tons/square mile/year; (2) a Holocene (11,000 years) yield based on the estimated volume of sediment in the Panoche Creek alluvial fan of 800 to 1,600 tons/square mile/year; and (3) an estimate of the suspended sediment transported past I-5 based on preliminary USGS 1998 streamflow gaging and sediment sampling data of about 15,000 tons/square mile/year.

Estimates of historical bed and bank erosion rates include: (1) a long-term bed-erosion rate in the one-mile-long reach of channel downstream from the confluence of 15,000 to 20,000 tons/yr per mile of channel; and (2) a bank erosion rate of 40,000 to 50,000 tons/year/mile of channel for the reach of channel near the confluence. The reach of channel used to derive these estimates has probably experienced the most severe erosion of any reach in the system, so these estimates should not be applied to the entire watershed. Comparison of the magnitude of these numbers, along with interpretations of recent field data, aerial photographs, and topographic surveys, suggest that bank erosion has recently been the dominant sediment-producing process in the lower watershed.

6.0 EVALUATION OF BEST MANAGEMENT PRACTICES

The overall objectives for implementing best management practices (BMPs) in the Panoche/Silver Creek Watershed are to reduce sediment delivery and the destructive effects of large flood flows on downstream areas. However, complete elimination of flood and sediment damage to downstream entities cannot be attained because of background (natural) erosion and the long-term effects of previous in-stream disturbances such as diversion dams and gravel mining operations. While reduction of damage may occur from implementation of appropriate BMPs, the actual decrease might not be accurately measured because, as for any natural system, watershed conditions change with time and the predictive capacity of non-point source/sediment delivery models is limited.

Although there are limitations inherent in an evaluation of sediment management and sediment load reduction BMPs for watersheds such as this 300-square-mile watershed, methodically evaluating BMPs allows for an objective assessment of the effects and benefits expected following implementation. Therefore, the BMPs which may provide the greatest benefit relative to cost can be advanced to the next stage of the implementation process, i.e., feasibility investigation/preliminary design activities for development of alternatives for sediment management. To evaluate potential BMPs in this assessment work, the following process was applied:

1) Description of each potential BMP (categorized as upland, riparian, or channel), including effectiveness, implementability, cost, and long-term maintenance requirements;

2) Recommendations of BMPs for various types of erosion features; and

3) Identification of strategic areas of the PSCW for implementation of specific BMPs.

To review BMPs on a larger scale, such as for the entire watershed (where appropriate), selected BMPs were linked in four different watershed-level combinations (scenarios) as described in Section 6.2. These four scenarios were evaluated, using the AGNPS or HEC-1 model, for their effect in reducing watershed sediment delivery and/or peak flow rate at the watershed outlet. Also, the scenarios were evaluated for implementability (high, moderate, low) and cost (high, moderate, low). Suggestions and guidance for future management practices and implementation projects are provided based on the results of this watershed-level evaluation.

6.1 BMP Characteristics and Potential Implementation

BMPs for the PSCW include "process" practices and structural practices. Examples of process practices include evaluation and adjustments of range management, developing incentives for preferred classes of livestock, and diversified monitoring efforts. Examples of structural practices include construction of grade controls, diversions, revegetation, invasive plant control, stream bank stabilization, contouring, and road paving. The descriptions provided below are arranged, first, according to major category of BMP (upland, riparian, or channel) and, second, according to structural or process-oriented approaches. Table 8 provides a summary of the BMPs in terms of effectiveness, implementability, and cost. Cost is listed as low, moderate, or high relative to costs for all other potential BMPs. On a per acre, per 1,000-foot stream reach, or per structure basis, “low” is associated with establishment costs of less than $2,000, and “high” is associated with costs of greater than $50,000. Costs between these two limits (i.e., from $2,000 to $50,000) are termed “moderate”.

6.1.1 Upland BMPs

The following discussion of upland BMPs includes their descriptions, and recommendations of BMPs for various types of erosion features and identification of strategic areas of the PSCW for implementation of specific upland BMPs.

Description of Upland Structural BMPs

Structural BMPs for reduction of erosion and runoff, as applied to upland areas, include: contour furrowing, soil imprinting, contouring, revegetation, soil stabilization, and road improvement. Descriptions, including a summary of effectiveness, implementability, cost, and long-term maintenance requirements, are provided below.

Contour furrowing would involve creating furrows at the toe of a slope or at a grade change in the slope, which would provide a drainage path for water to run across the contour and off the slope. This BMP would also shorten the slope length and reduce the velocity and volume of overland flow. While this BMP would be effective for reducing runoff and erosion, it would be difficult to implement on the steep hillslopes in areas needing erosion control measures. If implemented, contour furrowing could be performed using conventional farm equipment only in small areas because of the problems with access. The cost of this BMP would be low. Long-term maintenance requirements would probably be high because of the ongoing grazing and unstable soils in these areas.

Soil imprinting would create impressions in the soil surface for moisture retention and seed protection. Imprinting could be accomplished by a variety of mechanical implements, including bulldozer tracks, modified pipe, and culti-packer or sheeps-foot rollers. As well, the effect of hoof action in light to moderately grazed areas could be similar to mechanical imprinting techniques. However, erosion potential could be worsened from hoof action by overuse; an excessive amount of soil imprinting; and imprinting, compaction, and slippage by cattle during wet conditions. This BMP would be effective for reducing erosion and enhancing vegetative growth because of the surface storage created. Specialized or conventional farm equipment, as listed above, would be required for implementation; however, the same slope steepness difficulties with implementing contour furrowing would limit the applicability of soil imprinting. The cost of this BMP would be low. Long-term maintenance requirements would probably be high because of the ongoing grazing and unstable soils in these areas.

Contouring could involve a variety of cross-slope methods to shorten slope lengths on eroding slopes, slowing overland flows and retain moisture for seeded or planted materials. Contouring could be in the form of terraces, steps, or rolling terrain. Contouring would provide a similar level of effectiveness as compared to soil imprinting. Conventional farm equipment could be used for development of contouring. However, implementation would be limited by slope steepness in the critical, highly erodible areas. Because of the challenges with implementation on the steep slopes, the cost of this BMP would be moderate. Also, long-term maintenance requirements would probably be high because of the ongoing grazing and unstable soils in these areas.

Revegetation of areas of low vegetative cover that are subject to erosion and high runoff volumes would involve stabilization by the establishment of permanent, perennial cover in the form of seeded or planted native herbaceous species, shrubs, and trees. Implementation of this BMP is intended for those areas that do not have high selenium or low pH problems. Establishment of an adequate stand of perennial cover could require several growing seasons and would benefit from installation of fencing around these areas. Once established, and if maintained and not heavily grazed, permanent perennial vegetative cover would provide a self-sustaining, zero-maintenance form of erosion control. Not only would a revegetated area represent an effective method for erosion control, but it also would enhance and create wildlife habitat. Revegetation would be implementable with conventional seeding and planting methods. In areas of steeper slopes, dry or wet broadcast methods could be required. Using conventional equipment would result in low costs for implementing this BMP. However, steeper slopes could require the use of specialized all-terrain equipment, with an associated additional cost. Long-term maintenance requirements for revegetated areas would be minimal, assuming utilization of these areas is managed to prevent overgrazing.

Soil stabilization for highly erosive areas could be provided by temporary measures such as soil amendments or erosion blankets, or by permanent measures such as rock mulch. Technologies included in this BMP could include application of polymer stabilizing agents in high erosion source areas. This BMP represents an effective method of reducing erosion and decreasing the mobility of sediment from erodible hillslopes. Soil stabilization measures could be implemented with specialized equipment. If sprayed on as a stabilizing amendment, this technology could be applied in conjunction with revegetation efforts; conventional equipment, such as hydroseeders, could be used. For other soil stabilization technologies, implementation could only occur in relatively small areas due to slope steepness of areas needing treatment. The cost for materials and labor required to install soil stabilization measures would give this BMP a moderate cost for implementation. Unless done in conjunction with revegetation efforts, the long-term maintenance requirements for this BMP would be high.

Road improvement would involve stabilization of unpaved roads to reduce sediment contribution from these sources through measures such as paving roads receiving heavy use, or by placing gravel on more lightly used dirt roads. Runoff volumes could also be reduced on dirt roads by gravel placement. On roads built over clayey soils, pavement could be required to avoid rutting which could result in the transport of small amounts of sediment into streams. Road improvement would be effective in controlling erosion and sediment transport into surface water. However, based on the erosion inventory for the *study area*, road cuts are a relatively small source of sediment. This BMP would be implementable with conventional road construction equipment at a moderate cost. Long-term O&M requirements are expected to be less intensive than now required because of the increased stability of the improved roads.

<u>Description of Upland Process BMPs</u>

Process BMPs for reduction of erosion and runoff, in upland areas, would be applied to management of grazing systems and would include: continued annual assessment of Required Dry Mulch (RDM) levels; definition of target levels-of-condition for levels of soil erosion; diversification of RDM sampling areas; revision of RDM levels; implementation of a rotational grazing system; provision of economic incentives for preferred classes of livestock; creation of stewardship allotments; establishment of grass bank; and development of a CRMP-based range management plan. Descriptions, including a summary of effectiveness, implementability, cost, and long-term maintenance requirements, are provided below.

Continued annual assessment of RDM levels is needed to monitor the success of ongoing range management relative to the objectives. The only ongoing RDM monitoring work is currently conducted by the BLM on their grazing allotments. This BMP is implementable using existing staff, and is effective in monitoring and managing upland resources. Annual assessment of RDM levels, and review of data and adjustment of management decisions, can provide an iterative procedure for maintaining erosion control through prevention of overgrazing. Implementation would be low cost. Long-term commitment to this BMP is required for its success.

Definition of target levels-of-condition for levels of soil erosion would involve establishment of target levels for RDM levels, which would be defined according to conditions beyond which the soil erosion potential would be unacceptable. This BMP would involve establishment of an acceptable range of values to allow for seasonal variability. Although target levels are currently defined for RDM levels, it may be beneficial to define target levels specifically to address soil erosion. This BMP would be effective for targeting specific critical areas, and reducing the erosion potential of these areas which are exacerbated by heavy grazing, particularly in the lower watershed. Implementation would require funding of additional range/ecological support staff through the BLM, the CRMP, Fresno State, or other sources. If personnel are available, this BMP would be readily implementable, at a low cost. Long-term commitment to this BMP would be required for its success.

Diversification of RDM sampling areas would involve definition and identification of critical areas through increased diversity in sampling areas, which would be selected to reflect differences in soil type, aspect, and elevation. This BMP would probably involve a larger number of RDM sampling areas, relative to those currently monitored, to address the diversity of physiographic characteristics. However, monitoring RDM in this manner would probably provide a more effective means of reducing erosion from areas with high erosion potential. Implementation would require funding of additional range/ecological support staff through the BLM, the CRMP, Fresno State, or other sources. If personnel are available, this BMP would be readily implementable, at a moderate cost. Stakeholder involvement could give this BMP a low cost. Long-term commitment to this BMP would be required for its success.

Revision of RDM levels would involve adjustments to levels in critical areas to facilitate achievement of improved cover conditions, assuming an increase in cover would result in an improvement in non-point source water quality, as RDM levels are the primary means of providing soil cover on upland areas. Although current RDM requirements have been met, this BMP would be effective in addressing areas with higher erosion potential and the associated need for higher RDM levels in these areas. Implementation would require funding of additional range/ecological support staff through the BLM, the CRMP, Fresno State, or other sources. If personnel are available, this BMP would be readily implementable, at a moderate cost. Stakeholder involvement could give this BMP a low cost. Long-term commitment to this BMP would be required for its success.

Implementation of a rotational grazing system would involve alternating grazing on various pastures within the season of use to facilitate short-run achievement of target conditions, and also to help maintain these conditions in the long run. This BMP would be effective for improving conditions in critical areas, by not allowing grazing or congregating of cattle for extended periods of time. However, additional involvement of range management personnel would be required. Therefore, implementation would require funding of additional range/ecological support staff through the BLM, the CRMP, Fresno State, or other sources. If personnel are available, this BMP would be readily implementable, at a moderate cost. Stakeholder involvement could give this BMP a low cost. Long-term commitment to this BMP would be required for its success.

Provision of economic incentives for preferred classes of livestock would involve review of current BLM grazing regulations, with respect to stocking rate flexibility, and potential development of new incentives. This could involve preferential selection of livestock that are generally accepted to have lower impacts to sensitive areas. Livestock with “lighter” impact would include sheep and lightweight (350 to 400 pounds) steers. This BMP would be effective for reducing grazing impacts in critical areas and, thus, would reduce the potential for soil erosion in these areas. To be easily implemented, economic incentives would need to be developed and made available in an attractive manner to BLM permittees. Because of the need for economic and, in some cases, financial incentives, this BMP would have a moderate cost. However, the cost of this BMP would be low if the permit for a critical area is simply revised by the BLM. Long-term commitment to this BMP would be required for its success.

Creation of stewardship allotments could be offered as incentives to BLM permittees for excellence in stewardship of the range resource. Benefits of stewardship allotments for the permittee include deferred (end-of-season) billing and autonomy in management decisions. This may be one of the more effective BMPs for reducing erosion potential by improved management of grazing systems because it would involve more direct decision-making authority by the permittee, with a defined reward for sound management decisions. This BMP would be easily implementable at low cost. Long-term commitment to this BMP would be required for its success.

Establishment of a grass bank is a relatively new concept in which an alternate land area is purchased by a non-profit organization and offered to ranchers who need to maintain their herd while resting or developing improvements on their traditional allotments. This would preserve the economic viability of the ranching operations which are dependent upon the traditional allotments. Implementation of this BMP would allow impacted lands to recover, resulting in a reduction in erosion potential. Recovery of these lands could be either natural or in conjunction with an upland structural BMP such as revegetation. This BMP would be implementable only with additional public and/or private funding for the purchase of alternate land areas. Thus, the cost for implementation would be low to moderate. Long-term commitment to this BMP would be required for its success.

Development of a CRMP-based range management plan would involve a watershed-scale cooperative program to manage grazing of private and public lands. Although the BLM has developed a range management plan for their lands within the watershed, there has been none developed or applied in a comprehensive manner for the entire watershed. A watershed-based range management plan could be developed through cooperative efforts of the BLM, private landowners, the NRCS, Fresno State, and other stakeholders, and could be coordinated or administered by the CRMP. This type of plan would provide an effective venue for site-specific range management on public and private lands. Also, range management decisions could then be applied by the public and private landowners for the benefit of the watershed, addressing critical areas of high erosion potential on both public and private lands. This BMP would be easily implementable at a low to moderate cost. Long-term commitment to this BMP would be required for its success.

Recommendations of BMPs for Major Types of Upland Erosion Features

The following BMPs are recommended for cattle hoof disturbance and overland/rill erosion areas (the prominent types of features) in upland areas, based on relative effectiveness, implementability, and cost: revegetation; continued annual assessment of RDM levels; definition of target levels-of-condition for levels of soil erosion; creation of stewardship allotments; and development of a CRMP-based range management plan. The overall objective of applying these BMPs would be to reduce erosion potential for critical areas through increasing vegetative cover.

Identification of Strategic Areas of the PSCW for Implementation of Specific Upland BMPs

Strategic areas of upland BMP implementation would include those areas shown in Figure 6 as having an erosion rate of greater than 30 tons/acre for the existing condition. Adjacent areas with erosion rates of 20 to 30 tons/acre erosion rates would also be included in implementation of these BMPs. Public and private landowners in these areas would need to be involved in the process of designing and implementing these BMPs, which would need to be coordinated with grazing practices.

6.1.2 Riparian BMPs

The following discussion of riparian BMPs includes their descriptions, and recommendations of BMPs for various types of erosion features and identification of strategic areas of the PSCW for implementation of specific riparian BMPs.

Description of Riparian Structural BMPs

Structural BMPs for reduction of erosion and runoff, as applied to riparian areas, include: revegetation; saltcedar control; reclamation of the historical floodplain; and fencing. Descriptions, including a summary of effectiveness, implementability, cost, and long-term maintenance requirements, are provided below.

Revegetation would involve stabilization of erosive banks by establishment of permanent perennial vegetation in the form of native herbaceous and woody species. New plant material establishment could require several growing seasons, and would require regular monitoring and protection from livestock. Revegetation efforts could be targeted at two types of areas: (1) critical areas where infestation is heavy; and (2) areas that retain higher habitat values and are candidates for preservation. Revegetation would need to be coordinated with structural methods in areas of massive bank failure, and with saltcedar control in areas of infestation. This BMP would be effective for reducing peak flows and for filtering sediment, acting as a continuous "sediment trap" where present downgradient of steep, highly erodible hillslopes. Revegetation would be readily implementable. Once established, permanent perennial vegetative cover would provide a self-sustaining, zero-maintenance form of erosion control. Not only would a revegetated area represent an effective method for erosion control and streambank stabilization, but it would also enhance and create wildlife habitat. Revegetation would be implementable with conventional seeding and planting methods. Costs for implementing this BMP would be low. Long-term maintenance requirements for revegetated areas would be minimal, assuming utilization of these areas is managed to prevent overgrazing.

Saltcedar control would facilitate establishment of native vegetation in riparian areas and, therefore, contribute to the function of the riparian zone as a buffer, sediment trap, and streambank stabilizer. Dense saltcedar stands compete with native plant materials for available resources. Invasion of exotic species such as saltcedar replaces native riparian vegetation, thus, displacing native wildlife species by eliminating their habitat. Saltcedar also consumes large volumes of water, and may transpire as much as 200 gallons of water per day which would then not be available to support a diverse riparian vegetation community (Hughes, 1995). Like revegetation efforts, saltcedar control could be targeted at both critical areas and higher-quality habitat areas. Saltcedar control would be most effective if undertaken from upstream to downstream. This BMP would be effective, depending on the specific program selected, for improvement of conditions in which desirable species could re-establish. The costs for implementing this BMP would be low to moderate, and would require the use of heavy equipment and herbicides. After eradication of saltcedar and establishment of a desirable vegetative community, long-term maintenance would involve annual monitoring to identify and eliminate any observed saltcedar stand. To ensure long-term success for saltcedar control, this BMP would need to be implemented in conjunction with revegetation efforts, along with proper range utilization to prevent damage to newly planted vegetation.

Reclamation of the historical floodplain from I-5 downstream would be implemented as part of a land retirement program (Central Valley Project Improvement Act Land Retirement Program) that is currently under review by the U.S. Department of Interior Land Retirement Team. Floodplain reclamation would involve creation of a wide greenbelt corridor through which Panoche Creek would flow. This floodplain area would be separated from agricultural cropland by levees which would define the boundaries of the corridor. Overtopping of the Panoche Creek banks, downstream of I-5, during flooding currently impacts agricultural cropland and irrigation conveyance facilities. This BMP would be effective for reducing the current effects of flooding on agricultural land, and would be implementable with long-range planning and budgeting. The costs for implementation would be high. Long-term maintenance requirements would need to be evaluated under future study; such requirements could be high.

Fencing riparian areas in order to control livestock access could accelerate recovery of heavily impacted riparian areas. The fencing could separate pastures for separate management. Fencing plans would need to include annual maintenance for flood damage to in-stream fencing. Exclosure fencing design would allow for controlled, stabilized access to water. Fencing would be an effective BMP for reaching a desired ecologic condition in a given area, and for tailoring grazing to specific site requirements. This BMP would be easily implementable at moderate cost.

<u>Description of Riparian Process BMPs</u>

Process BMPs for reduction of erosion and runoff, as applied to riparian areas, include: implementation of sheep-only utilization of riparian pastures, and establishment of a grass bank. Descriptions, including a summary of effectiveness, implementability, cost, and long-term maintenance requirements, are provided below.

Implementation of sheep-only utilization of riparian pastures would involve limiting access in riparian zone areas to sheep, because they have less impact on vegetative cover and streambanks. This BMP could be applied selectively in critical areas. This BMP would be effective for reducing grazing impacts and, thus, could reduce the potential for streambank erosion. Also, vegetative cover would be increased, which would allow the affected riparian zone areas to trap sediment more effectively. This BMP would be easily implemented, but it might not be economically viable without some form of economic incentives or price supports. Without price supports, this BMP would have a low cost. However, a need for economic incentives could result in a moderate cost for implementation of this BMP. Long-term commitment to this BMP would be required for its success.

Establishment of a grass bank would involve the purchase of an alternate land area by a non-profit organization, and then offering this land to ranchers who need to maintain their herd while resting or developing improvements on their traditional allotments. This would preserve the economic viability of the ranching operations which are dependent upon the traditional allotments. Implementation of this BMP would allow impacted lands to recover resulting in a reduction in erosion potential and an increase in the riparian zone function as a sediment trap. Recovery of these lands could be either natural or in conjunction with a riparian structural BMP such as revegetation. This BMP would be implementable only with additional public and/or private funding for the purchase of alternate land areas. Thus, the cost for implementation would be low to moderate. Long-term commitment to this BMP would be required for its success.

Recommendations of BMPs for Various Types of Riparian Erosion Features

The following riparian zone BMPs are recommended to reduce erosion from sources which include gullying and mass wasting in or near streambanks. Other relevant BMPs would also provide a buffer or sediment trap between highly erodible hillslopes and stream channels. Recommended BMPs are selected based on relative effectiveness, implementability, and cost, and include: revegetation; fencing; and implementation of sheep-only utilization of riparian pastures. The overall objective of applying these BMPs would be to reduce erosion potential for critical areas, and improve sediment trapping or filtering through increasing vegetative cover. To address flooding and other negative impacts to downstream interests, including agricultural producers and the City of Mendota, reclamation of the historical floodplain downstream of I-5 may be effective as a long-term solution to control flood flows and therefore reduce flooding. Additional study should address the feasibility of such a corridor.

Identification of Strategic Areas of the PSCW for Implementation of Specific Riparian BMPs

Strategic areas of riparian BMP implementation would include those areas along streambanks where heavy utilization by cattle has been observed, specifically along Silver Creek upstream from the existing fenced area (beginning approximately 1.5 mile upstream from the confluence of Silver Creek with Panoche Creek) to the confluence of San Carlos and Los Pinos Creeks, which form Silver Creek. Public and private landowners in these areas would need to be involved in the process of designing and implementing these BMPs, which would need to be coordinated with grazing practices.

6.1.3 Channel BMPs

The following discussion of channel BMPs includes their descriptions, and recommendations of BMPs for various types of erosion features and identification of strategic stream reaches within the PSCW for implementation of specific channel BMPs.

Description of In-channel and Flow Control Structural BMPs

Structural BMPs for reduction of erosion and runoff, as applied to in-channel and flow control areas, include: channel reconfiguration; bank stabilization; revetment installation; temporary check dam installation; construction of permanent detention facilities; installation of small grade-control structures; and construction of a large flood-control dam near the confluence of Panoche and Silver Creeks. Descriptions, including a summary of effectiveness, implementability, cost, and long-term maintenance requirements, are provided below.

Channel reconfiguration in critical channel reaches would involve recreation of "natural" meanders to reduce scour, slow runoff event velocity, and enhance deposition of sediment. Sand and gravel bars in turn would offer appropriate growing medium for willow and cottonwood shoots, assisting regeneration of woody riparian vegetation. Channel reconfiguration could provide excellent potential for a functioning, self-sustaining stream system, but would require drastic disturbance in the initial work stages. This BMP would be effective for improvement of channel hydraulic and morphologic function, although design to accomplish a stable system would be a significant challenge because the stream systems in the PSCW are highly dynamic, especially in the lower watershed. It is likely that channel reconfiguration would require intensive maintenance and adjustment during the first several years in which flooding occurs. Thereafter, long-term maintenance requirements would probably be minimal. This BMP would be implementable with conventional construction equipment at a high cost. In-depth investigation would be required to determine the long-term viability of this BMP.

Bank stabilization in critical stream reaches or in livestock access areas could be provided in the form of "hard" treatments such as riprap or gabion baskets. These types of treatments would be integrated with woody or riparian plantings which could assist stabilization and enhance aesthetics. “Soft” techniques for bank stabilization could include log rolls, willow baskets, geotextile materials, and plantings of riparian vegetation. Bank stabilization would be an effective method for reducing streambank erosion. However, the overall effectiveness of the system may be limited by the ongoing natural processes and land use impacts such as cattle grazing at streambank areas, particularly in the lower watershed. This BMP would be best implemented in selected critical areas. Conventional construction equipment could be used, and the cost for implementation would be high. The high streambanks (40 to 50 feet) in areas of greatest bank erosion would also contribute to the high cost of this BMP. Long-term maintenance requirements could also be high because of the highly dynamic nature of the channels.

Revetment installation in the stream channel could assist stream recovery by slowing runoff velocities and creating pools where sediment may be deposited. Revetments would be constructed with natural materials, such as tree snags, or with riprap or gabions. This BMP represents an effective method for restoring channel functions, but the overall effectiveness to the system may be limited by ongoing natural processes and land use impacts such as cattle grazing at streambank areas, particularly in the lower watershed. This BMP would be best implemented in selected critical areas. Conventional construction equipment could be used, and the cost for implementation would be high. Long-term maintenance requirements could also be high because of the highly dynamic nature of the channels.

Temporary check dam installation, involving placement of straw bales or plastic fencing, could be implemented in critical areas to provide short-term erosion control and stabilization. These types of structures could be applied in areas where temporary stabilization is needed while permanent channel or riparian improvements are initially implemented, with their primary purpose being temporary control of sediment transport from highly erosive areas. This BMP represents an effective temporary method of short-term erosion control, and is readily implementable with conventional construction equipment at a relatively low cost. If these types of structures must be effective for an extended period, then the maintenance requirements would be low to moderate.

Construction of permanent detention facilities would involve development of detention facilities, or “dry” dams, in upper reaches of the watershed to reduce peak flow rates and, therefore, decrease the downstream flow velocities, depths, and resulting damage to streams and the surrounding floodplain associated with large rainfall/runoff events. These dams could be placed in upper reaches of the stream system where precipitation is highest. In these areas, sediment accumulation would be minimal, thus precluding the need for intensive maintenance and requiring only occasional sediment removal. If the structures are placed in lower stream reaches, or in reaches characterized by unstable soils, annual maintenance would be required, probably including removal of accumulated sediment. The dams would detain runoff water during and immediately after the storm, releasing it downstream at a slower rate over a longer period of time as compared to natural flow. Therefore, the volume of flow would be similar to the runoff event under existing conditions, but the maximum flow rate and associated floodwater depth would be decreased. With decreased flow depth in Panoche Creek, the total sediment load would also be expected to decrease. This BMP would be effective for reduction of peak flood flow rates and resulting damage to streams and floodplains during major flood events. The relative effectiveness of permanent detention facilities would depend on the size of these dams with respect to the drainage area upstream of each. These detention facilities would be readily implementable with conventional construction methods, and siting them would require geotechnical investigation. The cost of these structures would be moderate to high, depending on the size and number required to significantly mitigate flood flows in the lower watershed and downstream areas. To reduce regulatory requirements for dam construction and, therefore, overall cost, the dam size should be generally limited to the nonjurisdictional dam height of less than 25 feet and storage capacity of less than 50 acre-feet (Division of Safety of Dams, 1998).

Installation of small grade-control structures could offset channel incision by stabilizing steep channel gradients through the reduction of the streambed slope (grade) for defined lengths within a given reach, with an individual step (grade-control structure) separating each reduced-gradient length. Grade-control structures are constructed as a system through a critical reach, and are not recommended as single units. These permanent structures are expected to fill with sediment after a few runoff events, which is not believed to impair their effectiveness for grade control. This accumulated sediment is intended to remain in these structures; no sediment removal is required. In general, grade-control structures are an effective method of stabilizing headcutting channels, although their value for the PSCW may be somewhat limited because streambank erosion is the dominant process. These structures could be implemented at a low cost in some areas, but at a moderate or high cost in wide reaches of the stream channel. Conventional construction equipment could be used for installation. Long-term maintenance requirements would be minimal if the structures are installed correctly.

Construction of a large flood-control dam near the confluence of Panoche and Silver Creeks could provide storage capacity for a large volume of flood water and sediment. This BMP would involve construction of a single dam on Panoche Creek, just downstream from the confluence of Panoche and Silver Creeks, with controlled outlet works to discharge a percentage of the flood flow rate. The reduction of peak flow rate would result in potentially decreased streambank erosion, as would construction of permanent upper watershed detention facilities (discussed above). However, the main advantage of a single large dam in the lower watershed, relative to several smaller upper watershed structures, would be an increased control of flow to reaches downstream from the confluence. The reservoir of impounded water would also serve as a sediment trap and settling basin, which would reduce the long-term effectiveness of this BMP. A large amount of long-term O&M would be required to remove deposited sediments because of the large amount of sediment loading and transport in this reach during flood events. If considered further, feasibility evaluation of this BMP would require additional geologic/geotechnical investigations for site suitability, and sediment transport/deposition and maintenance evaluations for operability. Construction of a single dam structure could be implemented at a high cost. Conventional construction equipment could be used for installation. A dam of this size would be within the jurisdictional dam size, as defined by the Division of Safety of Dams (1998), and would have additional costs associated with meeting the regulatory requirements.

Recommendation of In-Channel and Flow Control Structure BMP

Construction of permanent detention facilities is the recommended in-channel and flow control structure BMP to reduce erosion of streambeds and streambanks in the watershed, as based on the relative effectiveness, implementability, and cost for this type of BMP. The overall objective of applying this BMP would be to reduce flood flow rates and depths, thus decreasing the potential for streambed scour and streambank erosion. While in-channel structures, such as bank stabilization and revetment measures, are intended to provide protection against streambank erosion in the channel reaches most susceptible to erosion during sediment transport events, these measures are not believed to be effective on a long-term basis. Permanent upper watershed detention structures, however, are believed to be effective for controlling the flow rate and depth during these short, sporadic episodes. Consequently, the reduction in flow rate and depth should decrease the velocity and height of water contact on the vulnerable streambanks during these events.

Identification of Areas of the PSCW for Implementation of In-Channel and Flow Control Structure BMP

Strategic areas for implementation of this BMP would include locations in the upper watershed where soils are stable and sediment sources are not significant. Potential sites would need to be identified and geotechnically investigated to determine suitability for permanent small dam structures. Also, additional hydrologic and hydraulic analyses would be needed to evaluate the actual effect of such dams, and the required sizes for various drainages. Public and private landowners in these areas would need to be involved in the process of designing and implementing these BMPs.

6.2 Watershed-Level BMP Scenarios

Four scenarios or combinations of BMPs were quantitatively evaluated for effectiveness in reducing sediment loading and/or reducing peak flood flow rates. The watershed outlet, which coincides with the USGS Panoche Creek/I-5 stream gaging station, was chosen as the location for comparison of runoff and erosion parameters. An additional evaluation of implementability and cost was also conducted, as discussed below. Changes in interrill and rill erosion processes, as affected by upland and riparian BMPs, were simulated using the AGNPS model. Implementation of in-channel flood flow detention structures in the upper watershed was simulated using the HEC-1 model (COE, 1991). For each model, the effects after implementation of the BMP scenario were compared with the existing condition "baseline" model simulations.

The four BMP scenarios were developed to represent reasonable, implementable changes to the watershed through selected management and structural BMPs, as described in Section 6.1. Only those BMPs which are viewed as readily implementable were included in the four scenarios. A summary of the potential effectiveness of each scenario for reducing the peak flow rate and total sediment yield at the watershed outlet for a 100-year, 48-hour storm is shown in Table 9. Discussion is also provided with respect to potential additional BMP scenarios that were not included in the watershed analysis.

BMP Scenarios #1, #2, and #3 were evaluated using AGNPS for comparison of the effects of these BMPs on total sediment yield at the watershed outlet. BMP Scenario #4 was evaluated using HEC-1 for comparison of the hydraulic effects of implementing runoff detention facilities in the upper watershed. Peak flow rates for these two models are not identical primarily because precipitation depths input in HEC-1 more accurately represent the larger depths associated with higher elevations and smaller depths in lower elevations, whereas, a uniform precipitation depth for the watershed is input in AGNPS. The use of an average, uniformly-distributed precipitation depth for the watershed is expected to place difference emphases on sources and runoff from the lower and higher elevations. However, there is not sufficient information to state if the results from AGNPS are over-estimates and, if so, by how much, although erosion sources in the lower watershed are expected to be over-estimated and runoff sources in the upper watershed to be under-estimated. Overall, the HEC-1 model is believed to more accurately represent the peak flow rates and hydrologic effects for the 100-year, 48-hour storm.

BMP Scenario #1

Scenario #1 involves application of the recommended upland BMPs in selected areas of the lower watershed. Major components of this scenario include: revegetation of upland areas which have low vegetative cover, and modification of grazing management practices to increase vegetative cover in critical upland areas. A combination of several selected upland process BMPs could be applied to develop this scenario. Vegetation cover was assumed to be increased in areas currently with less than approximately 20 percent cover. These revegetation areas are limited to the southeastern portion of the *study area* where high erosion rates are most prevalent relative to the rest of the watershed. A total of approximately 8,500 acres would be revegetated in this scenario, as shown in Figure 14. Relative to the existing condition, modeling in AGNPS shows virtually no change in peak flow rate at I-5, and an approximately 17 percent decrease (from 88,690 to 73,540 tons; values based on modeling only, not from measured data) in predicted total watershed sediment yield. However, this change is small when compared to the much larger magnitude of streambank and streambed erosion.

The management and structural improvements which are part of this BMP scenario are readily implementable in upland areas, where selenium and pH are not limiting factors, and the cost would be low to moderate. Because of the large area involved, implementation could be done using a phased approach in which the most highly eroded hillslopes would be revegetated first. Grazing practices would need to be modified in conjunction with revegetation efforts to avoid major disturbance of newly revegetated areas.

BMP Scenario #2

Scenario #2 involves application of the recommended riparian BMPs along Silver Creek where grazing effects have been noted. Major components of this scenario include: revegetation of riparian areas that have sparse vegetative cover, and modification of grazing management practices to increase vegetative cover. Implementation of sheep-only riparian pasture utilization would be the most appropriate management BMP for application in this scenario. To simulate this scenario in AGNPS, a zone adjacent to both sides of Silver Creek was designated to be a buffer or sediment trap, reducing the amount of sediment which reaches the streams from hillslopes in this area. A total of approximately 2,800 acres would be revegetated in this scenario, as shown in Figure 14. Relative to the existing condition, modeling in AGNPS shows virtually no change in peak flow rate at I-5, and an approximately 20 percent decrease (from 88,690 to 71,290 tons) in total watershed sediment yield. However, this change is small when compared to the much larger magnitude of streambank and streambed erosion.

The management and structural improvements which are part of this BMP scenario would be readily implementable in riparian areas at low to moderate cost. Because of the large area involved, implementation could be done using a phased approach in which the most sparsely vegetated riparian areas would be revegetated first. Instead of sheep-only pastures, other potentially appropriate BMPs to limit disturbance by cattle could include fencing. These grazing practices would need to be modified in conjunction with revegetation efforts to avoid major disturbance of newly revegetated areas.

BMP Scenario #3

Scenario #3 involves combining Scenarios #1 and #2. The total area revegetated would be approximately 11,300 acres in this scenario. Relative to the existing condition, modeling in AGNPS shows virtually no change in peak flow rate at I-5, and an approximately 28 percent decrease (from 88,690 to 64,250 tons) in total predicted (not measured) watershed sediment yield. However, this change is small when compared to the much larger magnitude of streambank and streambed erosion.

The management and structural improvements which are part of this BMP scenario would be readily implementable in upland areas, and the cost would be low to moderate. Because of the large area involved, implementation could be done using a phased approach in which the most highly eroded hillslopes and sparsely vegetated riparian areas would be revegetated first. Grazing practices would need to be modified in conjunction with revegetation efforts to avoid major disturbance of newly revegetated areas.

BMP Scenario #4

Scenario #4 involves application of the recommended in-channel and flow control structure BMP (detention facilities) in the upper watershed, which is where a large volume of runoff originates because of the larger precipitation depths relative to the lower watershed. The objectives for implementation of this BMP are to reduce peak flood flow rates, decrease flood stage, and reduce damage to downstream areas during floods. To simulate this scenario, seven in-channel detention facilities were simulated in different drainages of the upper watershed as shown in Figure 14. For purposes of this study, the potential dam locations are hypothetical. HEC-1 was used for evaluating the effect of these detention facilities because of the model's capability to reliably simulate the hydrologic and hydraulic effects from the temporary impoundment of water. However, HEC-1 does not quantify the effect of the impounding facilities on sediment yield. Therefore, total sediment yield was not simulated for BMP Scenario #4. For simulation of the effect of seven detention facilities in the upper watershed, HEC-1 input files originally developed by Boyle (1992b), and obtained from the NRCS for the current assessment work, were modified. Each detention facility was assumed to impound water to a maximum depth of 20 feet at a maximum impounded surface area of 40 acres.

Relative to the existing condition, HEC-1 modeling for this scenario shows an approximately 23 percent decrease (from 26,130 to 20,030 cfs) in peak flow rate at I-5 for the 100-year, 48-hour storm. This predicted change is viewed as reliable, because HEC-1 accounts for spatial variability in rainfall distribution and hydraulic routing of flows in the watershed. However, in the context of sediment yield, the effect of BMP Scenario #4 cannot be readily determined. Nonetheless, streambank erosion and in-channel production of sediment, which are the principal sources of sediment in the watershed, are expected to be reduced as a result of a decreased height of floodwater and potentially decreased flood flow velocities.

Construction of permanent detention facilities in the upper watershed would be readily implementable at moderate to high cost, as discussed in Section 6.1. This BMP would be effective for reducing the peak flow rate at the watershed outlet and, therefore, downstream of I-5. As part of the design, specific potential sites for detention facilities would need to be evaluated for geotechnical characteristics (to address issues which include geology and erodibility), size allowances, hydraulics, hydrology, and general feasibility issues, including government regulations, accessibility, and landowner agreements. To save cost, Division of Safety of Dams (1998) requirements should be reviewed to ensure that each detention facility is within the nonjurisdictional dam size. Additional detention facilities may be warranted to provide adequate temporary flood storage while preventing exceedance of the nonjurisdictional dam height and storage capacity.

Additional Potential BMP Scenarios

Additional potential BMP scenarios that were not evaluated, but may be viable in part or as a whole, include the following: major in-channel work to improve stability; construction of a dam near I-5 to impound water and settle sediment, with periodic removal of sediment for use as a construction material; and development of a floodplain corridor. These alternatives were not evaluated because of the uncertainty in the overall effectiveness of the system as affected by the ongoing natural processes. However, additional evaluation of these alternatives may be warranted during the feasibility investigation/conceptual design which would follow the current assessment work.

6.3 Recommendations

The recommendation for BMP implementation is a two-tiered approach, the first to address upland and riparian sediment source areas, and the second to address in-channel and streambank sources. In addition, further focused investigation into the feasibility of a corridor downstream of I-5 is highly recommended. Based on the results of the current assessment work, the first component would involve revegetation combined with modifications of grazing practices in the highly erodible upland and sparsely vegetated riparian areas (BMP Scenario #3). Implementation of this scenario would restrict erosion from upland source areas and provide a riparian buffer for transport of sediment into streams. However, as noted above, implementation of this scenario would result in only a relatively small change in total sediment yield when considering the large amount of streambank and streambed erosion which occurs during major runoff events. To maximize effectiveness, re-establishment of a vegetative riparian buffer area should include fencing exclusion and saltcedar eradication.

The second component would involve construction of detention facilities in the upper watershed (BMP Scenario #4). Implementation of this BMP scenario would result in reduced peak flood flow rates and decreased flood stages. Streambank erosion and in-channel production of sediment are expected to be reduced as a result of a decreased height of floodwater and potentially decreased flood flow velocities. Therefore, this scenario would result in a larger benefit in terms of reducing total sediment yield from the watershed. A detailed feasibility investigation is recommended for BMP Scenario #4 prior to implementation at specific locations. Geotechnical analyses, which will address geology and erodibility issues, should be required and included in these investigations. To save costs, Division of Safety of Dams (1998) requirements should be reviewed to ensure that each detention facility is within the nonjurisdictional dam size.

Implementation of BMP Scenarios #3 and #4 would involve the use of conventional construction methods and equipment, and the associated costs would be low to high. It is expected that both scenarios could be implemented concurrently because they apply to different portions of the watershed. Permits may required from the California Department of Fish and Game, the U.S. Army Corps of Engineers, the California Department of Water Resources, and others, prior to implementation.

Long-term operation and maintenance (O&M) requirements for these BMP Scenarios #3 and #4 are expected to be minimal. Revegetation in the lower watershed should be stable on a long-term basis if the personnel involved are committed to continual management of the rangeland, with modifications as necessary to adjust the approach for changing conditions. Detention facilities in the upper watershed should require only limited long-term O&M. Significant sediment accumulation upstream of these structures is not expected if they are located downstream of areas with low erosion potential. Therefore, the only O&M expected would be periodic (at least annual) inspection to ensure structural integrity of the dam for each facility, along with verification of a working outlet.

7.0 SUMMARY AND CONCLUSIONS

The overall goal of the Panoche/Silver Creek Watershed (PSCW) assessment was to provide the information necessary to make informed decisions on mitigation of the Panoche Creek sediment loading. This study was conducted according to the following objectives:

(1) Assess the rate of soil erosion from the PSCW, and identify influencing factors such as land use (agriculture, grazing, etc.) and natural processes;

(2) Identify and rank high erosion source areas;

(3) Evaluate the magnitude of sediment delivery into the lower fan area; and

(4) Develop and evaluate the effectiveness of best management practices (BMPs) for management of sediment production and reduction of sediment loads.

Assessment of the PSCW was conducted at three levels of detail and study effort, as shown spatially on Figure 1: (1) *watershed area*; (2) *study area*; and (3) *channel incision area*. The *watershed area* included all areas of surface drainage into Panoche Creek or Silver Creek, upstream of Interstate-5 (I-5), covering approximately 300 square miles; the *study area* consisted of an approximately 30-square-mile area, within which the confluence of Panoche Creek and Silver Creek is located; and the *channel incision area* extended from the Panoche Creek/Silver Creek confluence approximately 7 miles downstream, including a 2- to 3-mile distance downstream of I-5. The stream channel in the *channel incision area* is highly dynamic with areas of recent severe bed and bank erosion, as well as reaches experiencing considerable deposition. Unstable streambanks also exist in other portions of the lower and upper watershed.

Literature and data from previous studies in the watershed and surrounding area were obtained and reviewed for the PSCW assessment work. Major types of literature and data included: aerial photographs, previous reports, stream gaging data, and digitized mapping information. This information was reviewed to summarize watershed-level characteristics, erosion sources, channel geomorphology, and previous estimates of sediment yield. Through the review, data gaps and technical approaches to fulfill the four objectives were identified. A technical approach was then developed to perform the *watershed area* reconnaissance, *study area* characterization, *channel incision area* study, and erosion modeling studies. Results of the watershed assessment are summarized below.

7.1 Watershed Area Reconnaissance

The principal source of sediment transported to the lower Panoche Creek fan results from streambank and streambed erosion. This source accounts for the majority of sediment yield from the watershed, with much of this erosion occurring near the confluence of Panoche Creek and Silver Creek. Based on the results of the modeling, field observations of upland erosion features, measured sediment load data, and evaluations regarding channel erosion, the overall contribution of sediment from upland erosion features is minor relative to the total sediment load.

Grazing was evaluated because of its potential to influence erosion in the watershed. In general, the grazing pressure in the upper watershed was less than in grazed areas of the lower watershed. Exceptions to this were noted in the Vallecitos area, near the confluence of San Carlos and Larious Creeks, where the upland, riparian, and some channel areas appeared to be grazed heavily. All other parts of the upper watershed appeared to be less impacted from grazing than in the lower watershed. Also, in the lower watershed, the south end of Panoche Hills did not appear to be grazed heavily. Streambanks which appeared to be susceptible to bank erosion were generally associated with areas of deep channel incision. The Panoche Creek channel appears to become more stable with distance upstream from the confluence, although incision and related streambank erosion is still evident up to its confluence with Griswold Creek.

The riparian zone in the upper watershed was well vegetated with annual grasses and dryland shrubs except in minor areas of heavy grazing as noted above. Riparian zone vegetation in the upper watershed was generally more evident than the almost non-existent riparian vegetation in the lower watershed. Upland pastures in the upper watershed were generally well vegetated, in excellent condition, while lower watershed pasture conditions varied widely, from excellent on selected upper slopes areas to poor in many drainages. The watershed sub-area with the greatest impact from grazing appeared to be along Silver Creek, where a large amount of trampling was observed on streambanks, along with heavy trailing and little to no grass cover. A large extent of saltcedar (*Tamarix* spp.) invasion along Silver Creek was also observed.

An erosion hazard rating map was developed based on erosion modeling and field observations. Natural erosion processes, occurring on naturally susceptible hillslopes with steep slopes and sparse vegetative cover, are the primary influences resulting in high erosion rates in Griswold Canyon, the hills near Idria, and the lower Panoche Hills west and north of the confluence area. The northern Tumey Hills area also appears to be naturally susceptible to erosion, but there is an apparent additional influence of range utilization in this area, where high erosion rates are also predicted.

7.2 Study Area

Adverse impacts associated with livestock utilization in the PSCW assessment *study area* (which includes the Silver Creek Allotment) were noted for the 1998 season. These impacts were concentrated along drainages in the majority of both upland and riparian areas of Silver Creek. Bank erosion and incised channels appeared to be correlated to trampling and heavy browsing concentrated around these numerous small drainages. Herbaceous plant cover was low to absent in some of the drainage bottoms, and adverse impacts to shrub populations (*Atriplex* spp.) were also noted. Low vegetative cover and trampling were also noted in the riparian area of Silver Creek, and appeared more severe than the same categories of impacts occurring in upland drainages. Much of the riparian vegetation along Silver Creek appeared to be heavily impacted by livestock congregation, thus contributing to bank erosion and disturbance of the native plant community. Upland slopes outside the heavily impacted areas were characterized by excellent cover, with a limited amount of erosion. In selected drainages, percent cover appeared to be excellent, allowing the drainage courses to function as buffers for any potential sediment contribution to the nearest downstream channel.

South-facing slopes in the lower watershed areas were typically partially to fully dominated by red brome (*Bromus madritensis* spp. *rubens*), while north-facing slopes tended to support a greater diversity of plant species. In drier years, south-facing slopes may have little to no vegetation. In some portions of the *study area*, such as in Panoche Hills, ungrazed barren slopes were observed indicating that geology and soils, and not an effect of grazing intensity or pressure, are the controlling factors that lead to development of these barren slopes. Also, annual precipitation is generally held to be a critical influence on percent plant cover in annual grasslands, and may cause as much variation as soils, aspect, or grazing pressure (McNaughton, 1968). Aspect and vegetative cover (from field observations), along with geology (from Bartow, 1996), also appear to be factors influencing erosion potential, particularly in the lower watershed. Land use (grazing) exacerbates the erosion potential in these lower watershed areas already vulnerable to natural erosion processes. Cattle hoof disturbance erosion features account for most of the upland areas with high erosion potential in the watershed, as based on the *study area* erosion feature inventory. Cattle hoof disturbance, however, occurred in only approximately 2 percent of the *study area*, which is equivalent to approximately 0.2 percent of the entire watershed.

In many portions of the *study area*, a pathway (i.e., stream or gully) for transport of sediment from upland sources was observed. One notable exception to this was a 3-mile reach of Panoche/Silver Creek near the confluence where an ungrazed, fenced area with continuous, dense grass cover was observed between the highly erodible hillslopes and the Panoche/Silver Creek channel. This area extends approximately 1.5 miles downstream from the confluence, along the southeast side of Panoche Creek, and approximately 1.5 miles upstream from the confluence, along the east side of Silver Creek. Along Silver Creek upstream from this reach, grazing of this riparian/upland zone was observed and appeared to coincide with gullied, deeply incised stream channels.

7.3 Channel Incision Area

The Panoche Creek *channel incision area* has experienced dynamic geomorphic change over the past 60 years. For this project, historical changes since 1924 were characterized, and geomorphic effects of 1998 floods were described. Upstream reaches of the *channel incision area*, near the Panoche/Silver Creek confluence, have been the site of tens of feet of incision and, more recently, severe bank erosion. Between the confluence area and I-5, the creek has incised, and bank erosion is occurring on the outside of bends. Sediment delivery from upland areas to the stream along this reach is minor compared with the sediment produced in the confluence area. Panoche Creek between I-5 and the California Aqueduct generally has been a reach of sediment deposition with only localized bank erosion.

Estimates of historical bed and bank erosion rates include: (1) a long-term bed-erosion rate in the one-mile-long reach of channel downstream from the confluence of 15,000 to 20,000 tons/yr per mile of channel; and (2) a bank erosion rate of 40,000 to 50,000 tons/year per mile of channel for the reach of channel in the confluence area. The reach of channel used to derive these estimates has probably experienced the most severe erosion of any reach in the watershed system, so these estimates should not be applied to the entire watershed. Comparison of the magnitude of these numbers, along with interpretations of recent field data, aerial photographs, and topographic surveys, suggest that bank erosion has recently been the dominant sediment-producing process in the lower watershed.

7.4 Evaluation of Best Management Practices

Best management practices (BMPs) were evaluated individually and in selected combinations (BMP scenarios) in terms of their effectiveness, implementability, and relative cost for reducing sediment loading in the PSCW upstream of I-5. To address management of sediment in areas downstream of I-5, a focused, detailed investigation into the feasibility of a floodplain corridor, or other BMPs, is highly recommended.

From the evaluation of BMPs, it was observed that revegetation in selected appropriate areas, in conjunction with modifications of grazing practices in the highly erodible upland and sparsely vegetated riparian areas in the Silver Creek drainage (BMP Scenario #3), would restrict erosion from upland source areas and provide a riparian buffer to reduce the transport of sediment into streams. However, implementation of this scenario would result in a relatively small change in total sediment yield from the PSCW compared to the large amount of streambank and streambed erosion that occurs during major runoff events. Therefore, a second component, construction of runoff detention facilities in the upper PSCW (BMP Scenario #4) was also evaluated to address the potential for streambank and streambed erosion. A preliminary analysis shows that implementation of runoff detention facilities may result in a significant (approximately 23 percent) reduction in peak flood flow rates and, therefore, decreased flood stages. Streambank erosion and in-channel production of sediment would be expected to be reduced as a result of a decreased height of floodwater and potentially decreased flood flow velocities. Therefore, permanent runoff detention facilities in the upper watershed, in conjunction with re-establishment of a vegetative riparian buffer area in the Silver Creek drainage, may provide a major benefit in terms of reducing total sediment yield from the PSCW.

A detailed feasibility investigation of BMP Scenario #4 is recommended. This evaluation should include a quantification of the effect of these facilities on reduction of downstream streambank and streambed erosion. Geotechnical analyses for specific potential detention facility locations should also be required and included in these investigations to address geology and erodibility issues. Division of Safety of Dams (1998) requirements should also be reviewed to prevent exceedance of the requirements for nonjurisdictional dam size, thereby, reducing the overall cost of this scenario. Implementation of BMP Scenarios #3 and #4 would involve the use of conventional construction methods and equipment, and the associated costs would be low to moderate compared to the other BMPs evaluated. It is expected that both scenarios could be implemented concurrently because they apply to different portions of the watershed.

Long-term operation and maintenance (O&M) requirements for BMP Scenarios #3 and #4 are expected to be minimal. The revegetation in the lower watershed should be stable on a long-term basis if the personnel involved are committed to continual management of the rangeland, with modifications as necessary to adjust the approach for changing conditions. Runoff detention facilities in the upper watershed should require only limited long-term O&M. Sediment accumulation upstream of these structures would not be expected if they are located downstream of areas with low erosion potential. Therefore, the only expected O&M activity would be periodic (at least annual) inspection to ensure integrity of each structure, along with verification of a working outlet.

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TABLES

FIGURES

APPENDIX A

AGNPS Input Information

APPENDIX B

DWR Precipitation Data and USGS Preliminary Data for Panoche Creek at I-5 Gage (February 1 - 9, 1998)

APPENDIX C

GIS Coverages Compiled and/or Developed for PSCW Assessment

APPENDIX D

Cross Section Plots from Channel Survey

APPENDIX E

Summary of Comments on the Draft Final Report